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LRAPP TEST BED
ARRAY CABLE FAILURE ANALYSIS (U)

30 JULY 1971

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SYSTEMS GROUP
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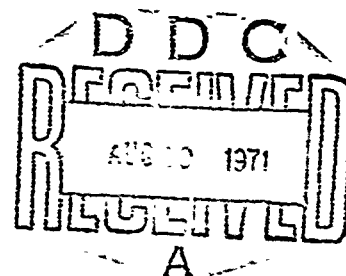
LRAPP TEST BED ARRAY CABLE

FAILURE ANALYSIS (U)

30 July 1971

Distribution limited to U.S. Gov't agencies only;
Test and Evaluation

Prepared for:
Office of Naval Research
Department of the Navy
Arlington, Virginia   22217

Code 469

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ABSTRACT

(U) This report is a diagnosis of the LRAPP Test Bed array cable failure. The high risk aspects of the Test Bed implantment that are identifiable with the array cable's properties or its handling are considered, and the particular cable properties which had major influence on the implantment are identified and their effect analyzed. Methods for retrieval of the Test Bed are then discussed and recommendations for enhancing the certainty of success for future suspended array implantments are suggested.

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APPENDICES

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1.0 INTRODUCTION

1.1 Background

(C) The LRAPP Test Bed was implanted in the Atlantic Ocean approximately 30 miles southeast of Bermuda in December 1970 by NUSC and its subcontractors on behalf of ONR. The Test Bed objectives, which were to support oceanographic, acoustic and engineering measurements, are described in references [1] and [2].

(U) Several days after the array had been laid, it went dead electrically. The array is now apparently intact but all communications with its instrumentation have been severed.

(U) Of pertinent interest to the LRAPP program at this time are answers to the following questions:

> (1) What caused failure of the Test Bed?
>
> (2) What should be done with the Test Bed now?
>
> (3) What has been learned from the Test Bed program?

1.2 Test Bed Description

(C) The Test Bed, shown in Figure 1, is a trapezoidal taut cable structure suspended 4,100 feet below the surface in 14,400 feet of water. Its configuration is achieved by cables, anchors and buoys. Both the 3,000 ft. horizontal array and the 14,500 ft. inclined legs are instrumented with acoustic and engineering sensors. The cable and attached instrumentation are rendered neutrally buoyant by glass spheres which were attached during payout at approximate 18 ft. intervals. Tautness is achieved by anchors and two corner floats, each having 2,500 lbs. buoyancy. The instrument locations are given in Table 1.

(C) A mushroom anchor and some 30,000 ft. of stable braid synthetic grapnel precede the offshore array anchor. The base of the inshore leg is connected electrically to NUSL, Tudor Hill by 43 NM of SDC List 1 unarmored coaxial cable and 4 NM of SDC List 5 armored shore cable. The interface between the double-armored array cable and the SDC is at the line driver, 500 feet before the inshore anchor.

1.3 Implantment

(U) The implantment plan called for payout from the offshore end inward. The 30,000 ft. of grapnel, which has a function primarily in array retrieval,

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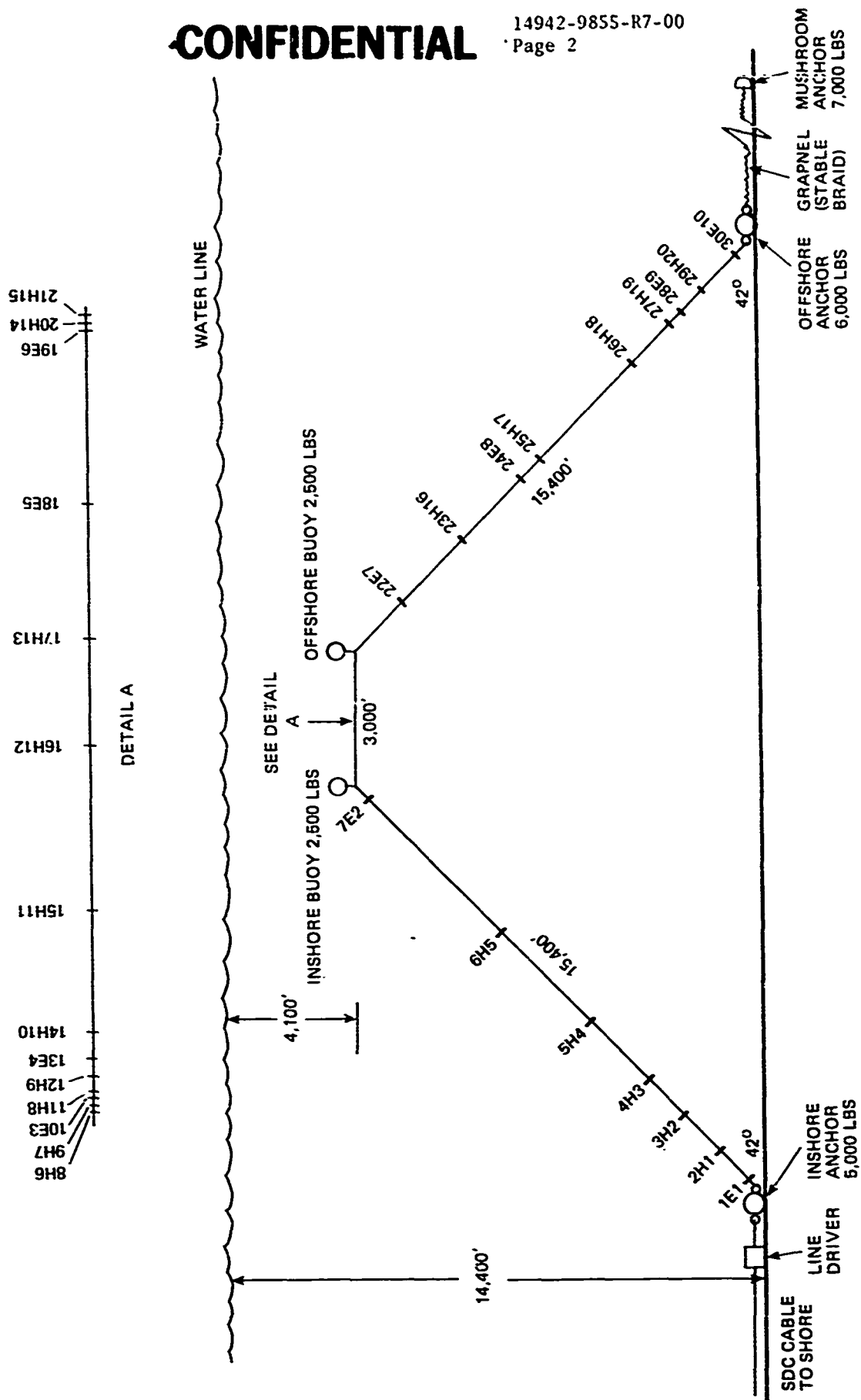
FIGURE 1. LRAPP TEST BED

TABLE 1.   LOCATION OF TEST BED INSTRUMENTATION

	STATION	LOCATION ALONG CABLE	DEPTH LOCATION (FT.)
--	LINE DRIVER	47 NM FROM SHORE	14,400
1E1	TENSION-INCLINOMETER	500' PAST LINE DRIVER	14,400
2H1	HYDROPHONE	50' ABOVE INSHORE ANCHOR	14,360
3H2		1,500'	13,350
7H3		2,700'	12,600
5H4		4,200'	11,600
6H5		7,640'	9,280
7E2	TENSION INCLINOMETER	11,680'	7,000
--	INSHORE BUOY	15,380'	4,110
8H6	HYDROPHONE	15,400'	4,100
9H7	HYDROPHONE	50' BEYOND INSHORE BUOY	
10E3	TENSION-DEPTH-CURRENT	70'	
11H18	HYDROPHONE	87'	
12H9	HYDROPHONE	100'	
13E4	ACCELEROMETER	175'	
14H10	HYDROPHONE	265'	
15H11	HYDROPHONE	360'	
16H12	HYDROPHONE	830'	
17H13	HYDROPHONE	1,430'	
18E5	ACCELEROMETER	1,830'	
19E6	TENSION-DEPTH-CURRENT	2,330'	
20H14	HYDROPHONE	2,910'	
21H15	HYDROPHONE	2,950'	
--	OFFSHORE BUOY	3,000'	5,550
22E7	ACCELEROMETER	13,230' ABOVE OFFSHORE ANCHOR	7,000
23H16	HYDROPHONE	10,060'	9,180
24E8	CURRENT METER	7,800'	9,300
25H17	HYDROPHONE	7,620'	11,600
26H18	HYDROPHONE	4,200'	12,600
27H19	HYDROPHONE	2,700'	12,680
28E9	CURRENT METER	2,350'	13,350
29H20	HYDROPHONE	1,500'	13,360
30E10	TENSION-INCLINOMETER	50'	13,400
--	OFFSHORE ANCHOR	33,800' FROM INSHORE ANCHOR	

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was laid with the help of a mushroom anchor having corrosive links. Implantment of the array itself commenced with payout of the offshore anchor and ended after some 19,000 ft. of SDC cable had been payed out, when the inshore array anchor reached the ocean bottom. With ensuing payout of 43 NM of SDC cable, the array was then connected electrically to NUSL, Tudor Hill as the SDC was spliced to the shore cable.

(U) The operation was carried out aboard the USS NAUBUC, whose features included excellent maneuverability and the capability of maintaining remarkably accurate positional control; however, its relatively small size rendered it vulnerable to pitching and heaving of considerable magnitude in high seas. Cable was payed out from the tank of the NAUBUC by means of a drum and fleeting knives with the help of a draw-off-hold-back (DOHB) machine. Details of the entire operation can be found in reference [3].

(C) Although the implantment was completed, several mishaps occurred.* The array cable developed a number of severe twists during payout, several of which visibly damaged the armor of the cable and had to be stress-relieved. One twist also produced an immediate electrical break which required extensive splicing in addition to a stress bypass. Several other twists apparently were "worked out" in going through the ship's machinery and were not stress-relieved. Just before touchdown of the offshore anchor an electrical short developed in the vicinity of one of these latter twists which, by this time, was well below the point of payout. Cable haul-in for repair was not considered feasible so the entire outboard leg had to be blanked out electrically. Finally, several days after the array had been implanted and within hours after the final shore splice had been made, another electrical short appeared about one-fourth of the way up the inshore leg, and the entire array went dead electrically.

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*Whereas much of the relevant factual information about events which occurred was not documented, it was necessary to interview personnel who were directly or indirectly connected with the program. A list of individuals contacted may be found with the list of references. All the information and opinion acquired at these interviews are contained in references [4], [5] and [6].

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1.4 <u>Scope</u>

(U) This report analyzes the LRAPP Test Bed failure, recommends re-
trieval procedures for the in-situ array, and suggests modifications for
future suspended array implantments based on what was learned.

(U) The diagnosis of Section 4 considers all factors of the implantment
which might have caused the array to stop functioning or which, in retrospect,
were undesirable from a risk standpoint. Those particular factors which can
be attributed to the array cable's mechanical properties or its handling are
identified and the specific influence of the cable's behavior is assessed.
Contributions to failure not directly attributable to the array cable but
rather to the implantment plan or to the overall operational plan are also
treated briefly in this section.

(U) Methodologies for retrieval of the Test Bed are discussed in Section
5. The merits and shortcomings alternate recovery procedures are given.

(U) Recommendations for the implantment of future arrays are then pre-
sented in Section 6. Experience gained from the Test Bed forms the basis for
several ideas advanced in this section.

(U) Appendices to this report deal with the cable handling from manfacture
to payout. They also include a narrative of training procedures for the implant-
ment and an account of program engineering. Irrelevant detail is generally
avoided, except to provide continuity in describing certain events.* The report
draws upon references [2] and [3] but does not duplicate information from these
sources unless it is germane to the discussion.

(U) Among the additional aspects of the array implantment program which
deserve examination are the hydromechanical components, the instrument packages
on the array cable, the instrumentation used for monitoring the implantment and
the overall program management plan. These subjects are outside the scope of
this report.

*A minute description is given of cable handling from manufacture to payout
because the information is not documented elsewhere or exists piecemeal.

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2.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

(U) Damage to the cable initiated by severe twisting during payout and aggravated by subsequent dynamic implantment stresses is the most likely cause of the known electrical shorts (Section 4.1).

(U) TRW's analysis indicates that the damaging twists were induced by the ship's payout machinery. Twisting forces are an unwanted side effect to the fleeting knives' designated function of guiding the cable path on the drum. The amount of twist introduced by the action of the fleeting knives is influenced by the frictional resistance of the cable's surface. The ability to accommodate this twisting depends on the cable's internal construction, particularly on its torsional strength and stiffness. Double armor cable, being susceptible to fleeting knife twisting forces by virtue of its bare armor surface, and having poor torsional compliance because of its high modulus exterior armoring, was therefore not suitable for the ship's payout machiner' or vice versa (Section 4.3).

(U) Other high risk aspects of the implantment were primarily associated with insufficient knowledge of the array cable's mechanical behavior (Section 4.4). Of particular importance is the propensity of cable to twist under tension. This phenomenon could have caused kinks in the cable subsequent to offshore anchor touchdown, or could have caused array entanglement during inshore anchor lowering (Section 4.5).

(U) Additional undesirable factors of the implantment included insufficient holding power of the inshore anchor (Section 4.6) and excessive oscillations of the cable-laying ship (section 4.7), both of which led to dynamic stressing of the array.

(U) Attempted retrieval of the array from the seaward direction might produce unacceptably high stresses on the inshore leg. These stresses would ruin any subsequent diagnostics of that leg and might even break the array cable (Section 5.2). On the other hand, attempted recovery from the inshore end will damage a portion of SDC and may break it in the vicinity of the array (Section 5.3). The best procedure appears to be haul-in from the shore cable splice outward if no future usage of the SDC in its present location is anticipated. Otherwise, the best recovery method is cable haul-in from the offshore

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end unless diagnostics of the array's structural integrity are considered vital. In this latter case the best method appears to be grappling for the portion of the array cable lying on the ocean bottom between the inshore anchor and the line driver, followed by retrieval from the offshore direction in case grappling cuts the cable before it reaches the ship (Section 5.5).

(U) The recovery ship should be large enough so as not to heave or pitch in adverse weather. Cable should be hauled in on power-driven reels, if possible. In any case the haul-in machinery should not be a drum and fleeting knives (Section 5.1).

(U) Future efforts should be directed toward a more streamlined payout process. This would include miniaturization of instrument packages, plug-in electronics and possibly, built-in buoyancy elements. The cable should be handled as little as possible and preferably on reels. Cable payout should be from reels, and the payout procedure should be reversible and capable of temporary interruption.

(U) The response of the cable to every phase of handling should be completely determined beforehand. The cable's properties should be compatible with its handling. A preliminary training period for the crew should include simulated implantment using prototype cable.

(U) Tolerances on cable twisting for both electrical and mechanical integrity should be determined beforehand. Torque relief should be provided at given intervals, if possible.

(U) The array configuration, cable buoyancy,and implantment procedure should be such that the cable never goes completely slack, especially after it has been under substantial tension of several thousand pounds. In fact, any abrupt changes in tension should be eliminated.

(U) The implantment plan should not call for lowering of anchors by more than one cable unless prototype experimental evidence shows no twisting.

(U) Finally, the cable-laying ship should be sizeable in order that its oscillations under adverse weather be minimal.

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3.0 DISCUSSION

3.1 Array Failure

(U) Strictly speaking, there were two identifiable failures* of tne LRAPP Test Bed:

(1) The array went dead electrically after 85 percent of the off-shore leg had been payed out. Diagnostics revealed an internal electrical short in that leg approximately 2,000 ft. up from the offshore anchor. Operational considerations brought about a decision to payout the remainder of that leg and then to open the array electrically. Consequently, the offshore leg was blanked out.

(2) Less than two hours after the SDC cable splice was made, the array started to deteriorate electrically. Voltage, current and resistance readings became abnormal and, finally, the array ceased to function electrically. This time diagnostics revealed a short to sea, located approximately 3,700 ft. up to the inshore leg.

3.2 Additional Considerations

(U) Diagnostics only of the observed failures and determination of their particular causes would not provide a complete picture of what went wrong with the Test Bed. Significant information missing from such an evaluation would be (1) additional failures which might have been identified had the above-described electrical shorts not occurred (2) aspects of the implantment which may not have brought about failure this time but which should be identified as high risk items and analyzed for purposes of improving the reliability of future implantments.

(U) In view of the above considerations, all factors of the Test Bed implantment which, in retrospect, were undesirable from a risk standpoint, will be identified and analyzed. As an aid in the performance of this task, all the significant mishaps and irregularities which were observed before and during implantment will be cited.

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*Whereas the array implantment was carried to completion, the term "failure" as used in this report only denotes events which caused the in-situ array to stop functioning.

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(U) The information presented in the next section represents a consensus of seven eyewitness accounts.* No observer individually cited each mishap accounted for, nor were the descriptions consistent with each other in all cases. Furthermore, action taken with regard to several irregularities which occurred during payout were not documented at all in a few instances. The chronology of events presented here was deduced by correlation of all information sources.

3.3 Mishaps to the Array Cable

(U) There were no significant array cable mishaps at any time from its manufacture (Appendix B), through array fabrication and assembly, to eventual loading aboard the NAUBUC (Appendix D). In fact, preliminary trial runs, described in Appendix C, appeared to indicate that the actual implantment would be achieved with little difficulty. Only two cases of cable twisting were observed in over a dozen cycles of payout and haul-in during the training period, and the twists straightened themselves out in both cases. Of course, significant differences between the trial runs and the actual implantment were that, during the former (1) no tests of the cable's electrical integrity were made (2) only 11,000 feet of cable were used (3) the practice cable was not quite the same as the prototype cable (see Appendix C for additional detail).

(U) The first operational irregularity occurred during loading of the array cable onto the NAUBUC. After approximately 11,000 feet had been loaded, a twist in the cable started building up on deck. The twist was relieved by unfastening a joint at the nearest instrument cage. Further loading of cable was accompanied by additional twisting, and on each occasion the twists were relieved as they were starting to build up. A total of 29 turns were relieved during the last 23,000 ft. of cable loading onto the NAUBUC. Additional details may be found in Appendix D.

(U) A large number of mishaps took place during actual cable payout. The points along the array where they occurred are shown in Figure 2 together with those of the identified electrical shorts. The nature of these irregularities may be described as follows:

(1) 2,000 ft. up the offshore leg. The cable went into the payout machinery as a hockle**. It came out of the machinery looking a

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*See References [4], [5], [6]
**The reader is referred to Appendix A for the nomenclature used in this document.
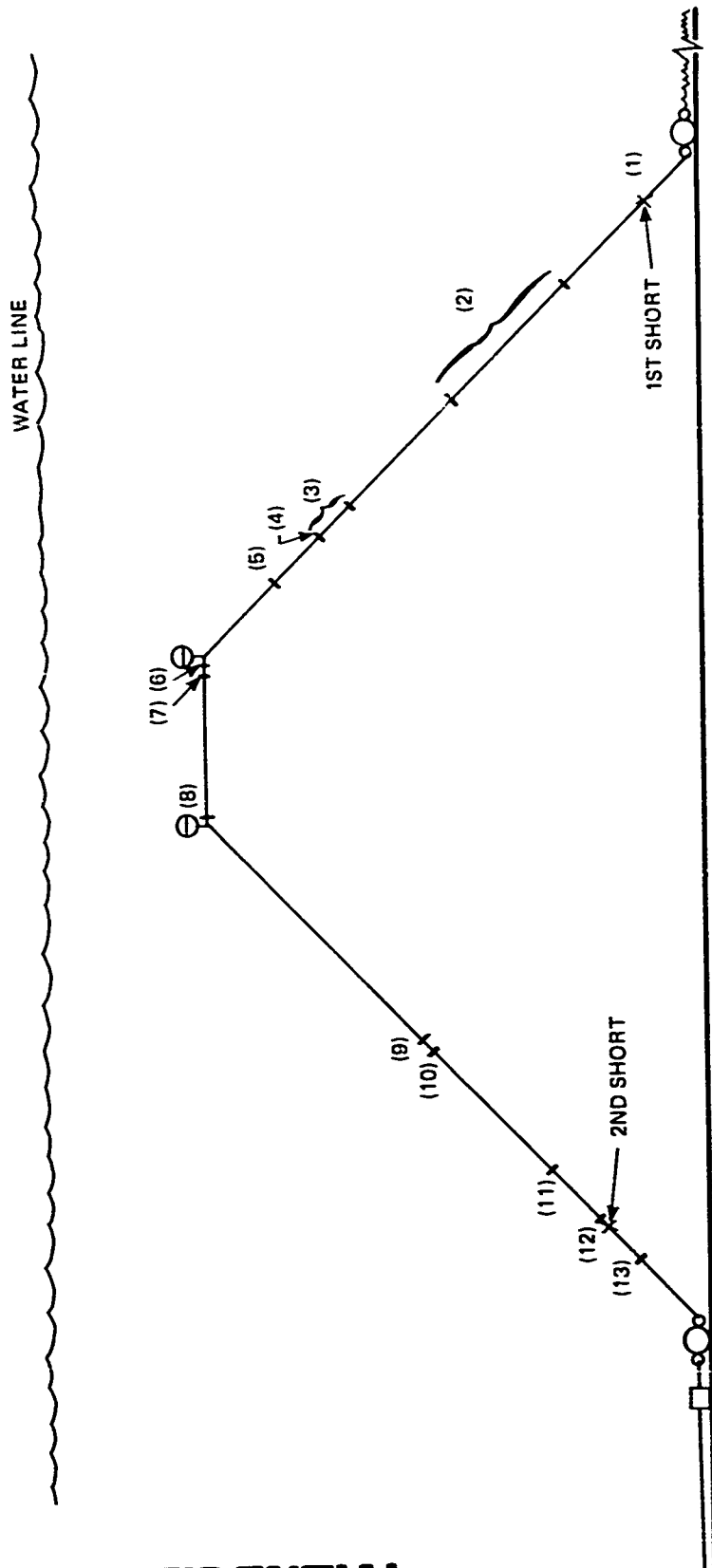
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FIGURE 2. LOCATIONS OF IMPLANTMENT IRREGULARITIES AND ELECTRICAL SHORTS

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little better than it did going in, as the outer armor tended to realign itself. There was no measurable change in the cable's electrical resistance, so preformed 24" splice rods were installed over the hockle and payout was resumed.

(2) Between instrument packages located 4,600 ft and 7,800 ft above the offshore anchor -- exact location not recorded. An electrical short developed (Pierce notes only [4]). There is no further mention of this problem in any of the logs.

(3) Between instrument packages located 11,000 ft. and 13,200 ft. above the offshore anchor. Cable was observed twisting in the tank. No further mention of this problem is made so it can be assumed that the twist distributed itself satisfactorily.

(4) 12,000 ft. up from the offshore anchor. A hockle formed in the tank and the cable came out of the machinery as a kink. There was no change in the cable's electrical resistance so it was merely stress-relieved at the kink by means of 3/8" wire rope and preformed grips.

(5) 13,250 ft. up the offshore leg at an instrument package. The array went dead electrically as this instrument package went over the drum. The electrical wire was purposely cut within the package and tested in both directions. There were no electrical faults looking shoreward. Looking seaward, a shield-to-outer-conductor short was detected, and its location was determined to be in the vicinity of the very first hockle. At this point the choices were to (a) haul back cable to the shore for repair (b) electrically terminate the array at the cut (c) proceed laying cable. The first possibility was ruled out because of the rough weather, the length of time it would take (including time to remove the glass spheres) and the lack of confidence in performing this tricky procedure successfully. The second remedy was discarded in favor of the third because the ship was heaving, cable tensions were quite high and it was only a short distance to the point where the offshore

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anchor would touch down and thereby relieve tension in the cable. Consequently, payout was resumed.

(6) 50 ft. inward from the offshore buoy. The array cable was opened electrically at this point.

(7) 350 ft. inward from the offshore buoy. A kink developed in the cable. There was no measurable electrical damage so the kink was stress-relieved with 3/8" wire rope using preformed grips and turnbuckles.

(8) Between instrument packages located 100 ft. and 70 ft. outward before the inshore buoy. There was very little length of flexible cable between splice rods. This fact is noted in reference [5] with no additional information. Apparently there was no noteworthy damage in this segment.

(9) Before the instrument package located halfway down the inshore leg -- exact location not specified. The payout process was halted in order to distribute twists along the cable. Payout was then resumed.

(10) 7,900 ft. up the inshore leg. A very bad kink occurred. In addition to the structural damage, the cable's electrical conductivity was broken. The entire segment of kinked cable was cut and the remaining cable ends were respliced electrically. The connecting segment was then overmolded to the armor outside diameter and taped.* Steel wire (probably 1/2" in diameter) together with deadeye stoppers and preformed grips provided a tension bypass for that segment. Payout was then resumed.

(11) 5,200 ft. up the inshore leg. Twists were developing in the tank. They were allowed to distribute themselves sufficiently and no hockles were formed coming out of the machinery.

(12) Just below the instrument located 4,200 ft. up the inshore leg. A severe twist was developing just before the DOHB was reached. Payout was halted and the twist was distributed down into the

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*The process actually included many more steps. They will not be described here.

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tank. The cable looked good coming out of the machinery so no splice rods were used.

(13) Just below the instrument package located 2,700 ft. up the inshore leg. The cable started twisting in the tank. The twist was redistributed by hand and the cable looked good coming out of the machinery. Again, no splice rods were used.

(14) At the SDC cable payout point calculated to correspond to the inshore anchor touching bottom there was no corresponding reduction in tension. Moreover, the depth gage showed the inshore buoy to be at 3,600 ft. depth -- in its final geometry it should have been at 4,100 ft. depth. Upon additional payout of SDC cable the inshore buoy rose to 3,570 ft. depth. Consequently, the ship started paying out SDC cable with negative slack till the inshore corner location stabilized at 3,800 ft. By this time the storm got so violent that tensions at payout never did drop to the range corresponding merely to the weight of the suspended SDC cable in water -- which would have indicated that the anchor had definitely touched down. Payout tensions during the next day of cable laying varied between 0 to 10,000 lbs. The final weighted chain attachment was not made because of the rough seas. The inshore array corner eventually held at 3,800 ft. depth as additional cable was laid.

(15) Within two hours after the shore cable splice, the entire array went dead electrically. This event is described in a previous narrative.

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4.0 ANALYSIS

4.1 Failure Identification

(U) Obviously the first electrical failure can be identified directly with the hockle which occurred 2,000 ft. up the offshore leg during payout (item (1) of section 3.3). Recall that there was no measurable deviation of electrical resistance across that hockle after going through the drum and fleeting knives. However, this measurement did not necessarily account for all possible internal damage initiated in the cable -- damage which could have been aggravated to electrical failure under the dynamic tension forces which followed. The preformed rods provided localized stiffening and tended to straighten out the cable at the hockle. However, they did not provide a total stress bypass. Whereas measured* tensions in the offshore leg were often substantial -- ranging as high as 14,000 lbs. -- the possibility of subsequent electrical failure at that hockle certainly existed.

(U) The short which eventually blanked out the entire array can be linked to at least one, and possibly three, excessive twists in the cable during payout. In particular, the diagnosed location of the short is very close to the severe twist which developed just below instrument 5H4, located 4,200 ft. up the inshore leg. In this case the cable "looked good" mechanically and checked out electrically coming out of the ship's machinery, so that not even splice rods were used. However, this particular twist may have initiated a condition that led to a short under subsequent stresses, as in the previous case discussed. Tensions in this leg just prior to inshore anchor touchdown would have been around 3,700 lbs. had this phase of the implantment truly been quasi-static. However, severe ship motion ** due to extremely rough weather produced dynamic cable stresses in the SDC ranging ± 50% about the nominal static values. Similar oscillatory stressing of the array cable inshore leg coupled with possible twisting and entangling effects due to torquing*** certainly could have aggravated a weakened section of cable to the point of electrical failure. Dynamic stressing may have been enhanced even further by in-situ motions of the inshore anchor.****

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*The measuring system for cable tension is discussed in Section 6.
 **See Appendix E for details.
 ***See Section 4.5
 ****See Section 4.7

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4.2 Additional Remarks

(U) Three observations are in order with regard to the failures and all other mishaps cited in Section 3.3:

(1) The damaging twists which occurred on deck were manifestations of incompatibilities between the array cable's mechanical properties and the manner in which it was handled.

(2) Failure of the inshore anchor to touch down was due to a deficiency in the implantment plan.

(3) Adverse effects of ship motion during rough weather was a shortcoming of the overall operational plan.

(U) The next few sections will discuss deficiencies in the implantment and the extent to which these deficiencies were due to the array cable properties, its handling, the implantment plan and the operational plan.

4.3 Influence of Cable Handling

(U) There is very little doubt that the severe twists which appeared on deck during payout were a major contributor to both electrical failures. Every stage of cable-handling from manufacture to payout has been traced in an effort to determine the causes of twisting. The most important clue to its source is the fact that loops appeared in the same cable while it was being loaded onto the NAUBUC. In fact,.a total of 29 turns of cable had to be relieved during loading (see Appendix D for details).

(U) After consideration of alternate possible causes of twisting (Appendix F), it appears that the phenomenon was due to the action of the drum and fleeting knives aboard ship. This assertion will now be justified.

Suppose the combined action of the 12 ft. drum and fleeting knives were to rotate the cable passing through it in a right hand direction at the rate of T turns per unit length (the hypothetical effect is shown symbolically in Fig. 3).
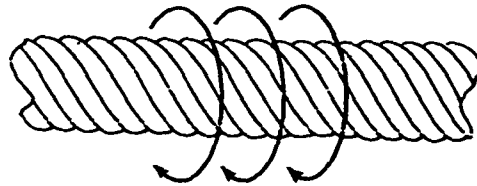
Figure 3. TURNS INDUCED BY THE DRUM AND FLEETING KNIVES

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If L is the total length of cable while X is the cable length which has
already passed through the machinery and is now almost completely in the tank
of the ship, then this latter segment will have been subjected to a uniform
twist of T turns per unit length. As for the remaining portion of cable,
a total twist of TX turns is now distributed over length (L-X). If this
twist were uniformly distributed over the remaining segment, its twist per
unit length would be

$$\frac{TX}{L-X}$$

It would reach the value T when X = L/2 and then get progressively larger
with increasing X (recall that no twists appeared during the first 11,000 ft.
of array loading). The result would be loops, or hockles if the remaining
cable length were in a state of tension. Furthermore, they would be in a direction
which tends to tighten the outer armor -- both the loops which appeared during
loading and the hockles which occurred during payout were right hand twists.

(U) Actually, the total twists TX will not distribute itself uniformly --
it will be greatest in the vicinity of the machinery, then would decay exponentially.*
Very little twist would be propagated beyond the first 2 or 3 windings in the
truck flatbed. Moreover, each instrument package, being both massive and stiff,
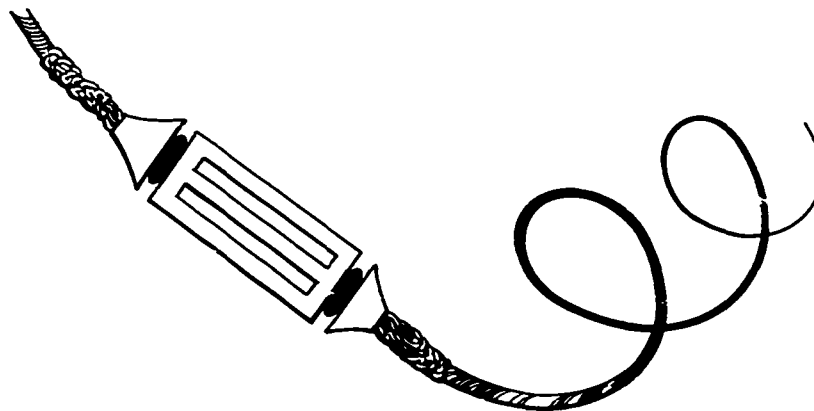would be a point of twist accumulation, as illustrated in Figure 4. Twisting,

FIGURE 4.   BUILDUP OF TWIST

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*This phenomenon is described in reference [7] with regard to torquing of SDC
 cable.

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in fact, did build up at instrument cages

(U) We believe that the ships machinery did impart twist into the cable
in the manner and direction shown during loading and that this is what caused
the 29 turns of cable to be relieved. Of course, we are not hypothesizing a
pure kinematical uniform twist per unit length, but are asserting that the drum
and fleeting knives exerted a twisting force on the cable that eventually
caused the loops.

(U) One consequence of this last assumption is that the cable loaded in
the tank of the ship probably had a small uniform twist in the left hand direction
superimposed upon that due to coiling. Suppose now that the same right hand
turn is imparted to the cable by the ship's machinery during payout. The residual
left hand twist is eventually overcome and, since the cable is now in a state
of tension going through the machinery, hockles occur.

(U) Now that we have come up with an explanation for the twists that fits
the occurrence of events, let us hypothesize how the drum and fleeting knives
actually impart the twist. The cable is wound around the drum and fleeting
knives in a right hand direction (Figure 5). In order to keep the cable moving
as indicated, the force of the fleeting knives must be in the vector direction
of drum rotation, which is towards the left in Figure 5. Otherwise the windings
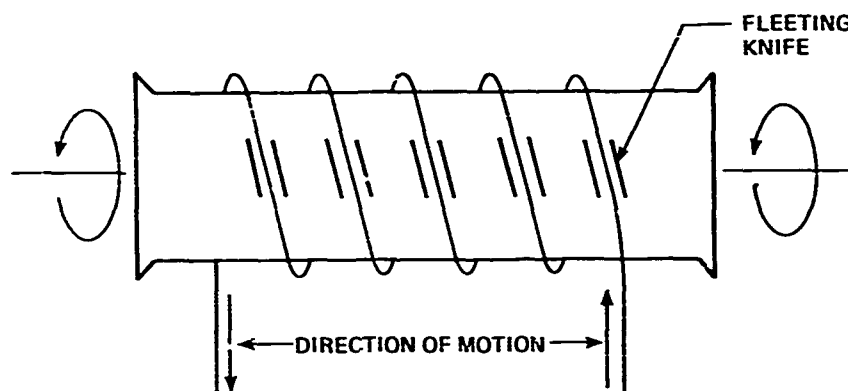

FIGURE 5.   ACTION OF DRUM AND FLEETING KNIVES

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would propagate towards the right as cable is being moved by the drum. The frictional component of the fleeting knives force then produces a left hand twist in the cable leaving the drum and a right hand twist back toward the direction where cable is coming from. The actual winding of the cable on the drum aboard the NAUBUC was right-handed as shown, so that the "back twist" was right-handed during both loading and payout. The directions of the loops which appeared during loading as well as the hockles which occurred during payout were also exclusively right-handed. Thus, the assumed twist mechanism is completely consistent with the account of events.

(U) We conclude this section with an attempt to relate the array cable's mechanical properties to the twisting effect of the ship's machinery. Whereas the fleeting knife nominal design forces are a function of net tension, number of cable turns and drum diameter, the unwanted frictional component producing the twist depends on the cable's diameter and on the smoothness of its outer surface. Moreover, the capacity of the cable to accommodate these forces depends on its mechanical properties. Obviously, the greater the twist the cable can take till mechanical or electrical failure, the better its ability to withstand these forces. In other words a high torsional strength - low torsional stiffness cable will accommodate the fleeting knives best. This explains why SDC List 1 cable, having its strength member at the center and being unarmored is suitable for the drum and fleeting knives. This was evidenced by the successful payout of 43 NM of SDC without any irregularities. On the other hand, double armor cable , having its bare armor in direct contact with the fleeting knives and having very little torsional compliance, was hardly suitable for this particular payout system, or vice versa.

(U) One final observation is in order: Cable is a structural material in tension only. It is very flimsy under bending, torsion or transverse shear. Being a very delicate material, it should not be subjected to random handling. One cannot handle cable in the same manner as a steel bar or a lead weight and then assume it has maintained its structural integrity for future usage. This is why cable is usually handled in a controlled manner, namely, on reels.

4.4 Influence of Array Cable Properties

(U) Cables* are intended to be used primarily for transmitting electrical

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*See Appendix A for the distinction between cable and wire rope.

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power. Particular applications often necessitate their additional use as load-carrying members. Examples of such applications for underwater cables are (1) mooring (2) towing (3) tethering (4) lowering (5) lifting (6) suspending. The Test Bed cable was intended for suspending hydrophones and engineering instrumentation in-situ whereas the array implantment procedure necessitated its use for lowering anchors as well. Furthermore, because the operational plan allowed for eventual array retrieval, the cable also had to be capable of providing the necessary lifting forces.

(U) The internal construction of cable varies widely from product to product. The structural properties of specific cables are usually not fully known nor is their behavior always predictable. Although there have been numerous publications on various aspects of cable [8] and wire rope [9] marine usage most of these papers have dealt with the dynamics of such members under hydrodynamic loading (see, for example, [10]) rather than with the materials or construction aspects of cable, or why cable may or may not be suitable for certain applications. Of special background interest here on the latter topic are references [11] - [21].

(U) The purpose of armoring cable is to provide both protection and added strength. The reason for reverse lay armoring is to provide torque balance also. It is possible to achieve mere added strength in coaxial cable by means other than armoring, for example, by using an inner conductor that is also a strength member. Such is the case with SDC List 1* cable where the inner conductor is a copper-jacketed steel strand of 41 wires. Armoring of cable gives it other distinguishable characteristics, some of which may be desirable for certain usage and undesirable for others. For example, its rough surface can be advantageous when used in connection with a capstan but is of no benefit during payout over a stern chute.

(U) Table 2 lists the particular structural loads on the array cable during every stage of its handling from manufacture to implantment. Observe that coiling and uncoiling operations in connection with leakage tests, transportation, and storage aboard ship subjected this cable to three cycles of combined bending and torsion.

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*See reference [7]

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TABLE 2. STRESSES AT ALL STAGES OF CABLE HANDLING

CABLE HANDLING PROCEDURE*	STRESS
Manufacture	Tension** and release
Cable wound onto reels	Tension plus bending
Cable transferred onto smaller reels	Maintain tension -- remove & reapply bending
Array fabrication	Remove tension and bending -- no provision for untwisting
Coil into tank for leakage test	Combined bending and torsion
Uncoil from tank	Remove bending and tension
Coil into truck flatbed	Combined bending and tension
Unvoil from truck flatbed	Remove bending and tension
Test instrument cages aboard ship	Tension and release***
Through drum and fleeting knives	Combined tension and bending, and possibly torsion
Through DOHB	Traction and lateral compression
Coil into tank of ship	Combined bending and torsion
Uncoil from tank of ship	Remove bending and torsion
Through DOHB	Traction
Through drum and fleeting knives	Tension and bending (and torsion?)
Over dynamometer	Combined tension and bending
Over stern plate	Combined tension and bending
Implantment	Tension -- possibly torquing
In-situ	Tension, posibly torsion also

*Certain insignificant loads have been omitted
**Stresses on individual wires during the manufacturing process will not be considered
***Not applicable to entire cable

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(U) Appendix G considers those structural properties of double-armored cable which are relevant to the loading cited in Table 2. The effect of the armoring is evaluated in each case and the ability of this particular cable to accommodate the applied loading is analyzed based on the extent to which its properties are known. Contributions to failure are then deduced and high risk items identified. The analysis indicates the following:

(1) Cable tensions at all stages stayed well within* the 30,000 lb. minimum breaking strength. Undoubtedly they also stayed within a range that would not damage a healthy cable electrically. However, this is pure speculation since these latter limits were not established.

(2) The integrity of the array cable under the traction and lateral compression of the DOHB is not known but the possible effects cannot be identified with any observed irregularity.

(3) The minimum radius to which the cable was bent never was less than the 12" allowable given by the manufacturer. This latter value seems to be based on experience rather than on controlled test data, but it seems to be a safe value based on the cable's bending compliance.

(4) There is no information on how much torque or twist the cable was subjected to, nor on the corresponding allowables, but the latter were obviously exceeded on several occasions. Excessive torsion was indeed the very mechanism of almost all the observed mishaps.

(5) Combined tension and bending, as in the case when cable is reeled, passed around a sheave, etc., can lead to electrical trouble due to "fileting" of the inner conductor through the insulation, or possibly due to crimping. The integrity of the array cable under these loads was not known and should be determined for future usage. However, no observed irregularities can be attributed to excessive loading in this manner.

(6) The cable was subjected to very minimal combined bending and torsion in the form of coiling, and appeared to accommodate this loading without any difficulty. The allowable limits for coiling were never established, but this does not appear to be important in view of the cable's response to these forces.

*See Appendix F

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(7) The cable was susceptible to "torquing," a phenomenon which is discussed in Section 4.5.

(8) Hysteresis properties of this cable were not at all known. They may have contributed to the formation of loops during loading and of twists during payout. However, this possibility is found to be unlikely in Appendix F.

4.5 Torquing

(U) Torquing is the propensity of cable to twist under pure tensile forces or to build up torque when subjected to pure extensional deformation. This phenomenon is of interest for several reasons:

(1) Cable coming off a manufacturing line is transferred onto reels under pretty high tension. The very nature of the manufacturing process allows the cable to twist all it wants to under this tensile force, that is, the cable is stored on the reel torque-free. On the other hand, this means that the cable coming off the reels should be permitted to untwist all it wants to unless the same tension is maintained. Failure to do so can mean a very lively cable in future handling.

(2) A heavy weight suspended by a cable, such as an anchor being lowered, will cause the cable to twist in accordance with its torque-balance characteristics. However, when this weight touches bottom, cable tension suddenly drops to zero and the cable wants to untwist. But now it is not free to untwist, so the resultant effect is loops in the tension-free cable. Upon subsequent reapplication of tension, the loops can become kinks.

(3) A heavy weight being lowered by two cables will produce torsional effects which can cause the cables to twist around each other. The scenario is obvious.

(U) For the above-described reasons, it is desirable to have a cable as torque-balanced as possible. The importance of this property in wire rope and cable for marine applications is discussed in references [20] and [21], where photos of cable failures due to lack of torque-balance are shown.

(U) We are fairly certain that there were no residual twists in the cable coming off the manufacturing line (see Appendix D'). Let us now identify

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phases of the implantment were torquing may have been a problem.

(U) Lowering of the offshore anchor puts the array cable in a state of torque-free tension. However, touchdown of the anchor is followed by a twist-free release of tension. With total slack in the leg, as was the case with the Test Bed, the tendancy to form loops as a means of torque relaxation (as illustrated in Figure 6) was certainly there. Furthermore, since tension in
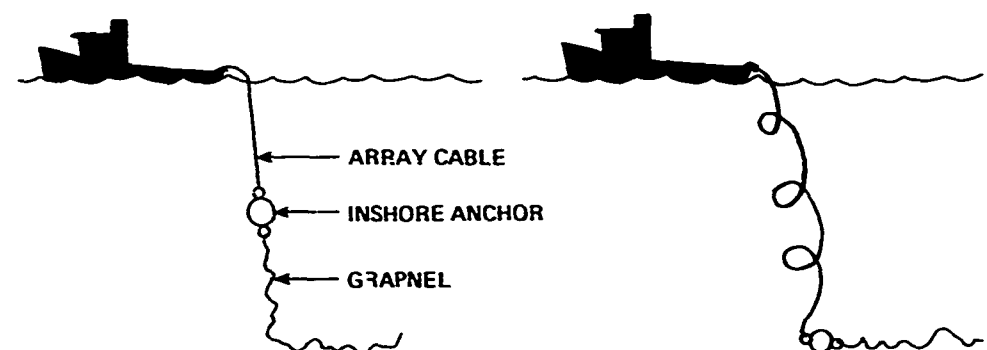

FIGURE 6. TORQUING DURING IMPLANTMENT

that leg eventually built up into the thousands of pounds again, kink formation was definitely a possibility.

(U) The second situation where torquing may have been a problem was during lowering of the inshore anchor. Here the effect would have been some-what different, since neither the array cable nor the weighted SDC cable were ever in a state of zero tension during or after lowering. With two cables suspending the anchor, as shown in Figure 7, any torquing properties of either cable would have caused spiraling of the two lengths around each other*, as

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*Unless the torquing tendancies of the two cables negated each other. This is highly unlikely.
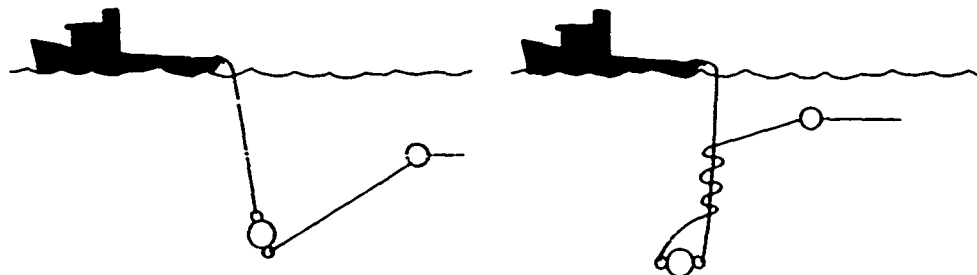
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FIGURE 7. ENTANGLEMENT DUE TO TORQUING

illustrated. The consequences could be entanglement of the glass spheres, instrument cages, etc., with resultant cable stresses possibly well beyond the design range. It would be futile to attempt to construct a failure mechanism under this cycle of loading should the array have indeed torqued. However, it is sufficient to say that any cable torquing tendancies great enough to have caused entanglement during lowering would have certainly made the entire procedure unacceptable from a risk standpoint.

(U) We can say for sure that torquing had nothing to do with the known electrical failure of the offshore leg because this event occurred before the offshore anchor ever touched down. We do not know what influence torquing had on the final failure or on any subsequent mishaps which cannot be identified.

(U) Specifications required the cable to twist no more than 2 turns per thousand feet under a 10,000 lb. tensile force. Data supplied by the manufacturer indicates the cable met this requirement* with no problem (see Appendix B). Maximum twisting below 10,000 lbs load was 1.6 turns per thousand feet and it took 12,000 lbs. load to finally achieve 2 turns per thousand feet. Note however, that this data was acquired from the cable's virgin state. There is no reason to expect the data to be reproduced after the cable has gone through the cycles of tension, bending, twisting and traction described previously.

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*No verification testing was carried out by the customer.

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(U) Finally, we observe that, even if the above data on the cable was accurate for the implantment, one cannot presently say if the twist resulting from torquing actually produced kinks or entanglement, or if it was merely accommodated by the cable. In the absence of any analytical criteria the tolerable level of torquing for this particular implantment can not be deduced without prototype experiments.

4.6 Influence of the Implantment Plan

(U) The most significant defect in the array cable implantment plan was manifested in failure to identify actual touchdown of the inshore anchor. Recall from Section 2.2 that there was no reduction in cable tension aboard ship at the SDC cable payout point corresponding to inshore anchor touchdown. In order to see why, let us consider forces on the inshore anchor just prior to touchdown. Assuming the array to be in its final configuration at this instant (Figure 8), we find from equilibrium considerations that the force of
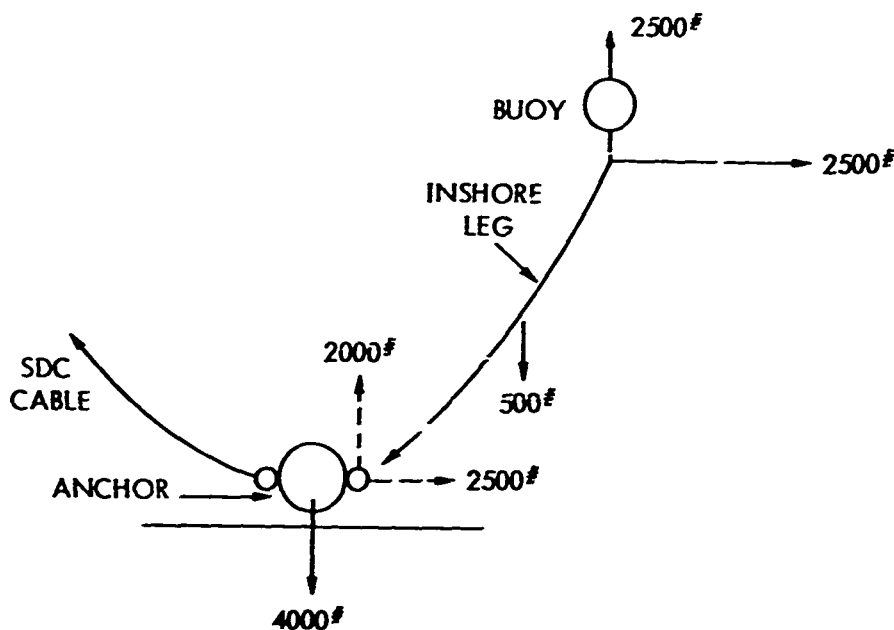

FIGURE 8.   INSHORE ANCHOR TOUCHDOWN

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the array leg on the inshore anchor has a 2,000 lb. vertical component (2500# buoy force - 500# negative cable buoyancy) and a 2500 lb. horizontal component. Since the anchor weight is 4,000 lb.*, the equilibrating SDC cable force on the anchor has a 4000-2000 = 2,000 lb. upward component and a 2,500 lb. horizontal component.

(U) As the anchor touches down and as the SDC cable is slackened, the normal force of the ocean floor on the anchor builds up from zero to 2,000 lb. as the SDC cable force diminishes. However, the frictional force on the anchor must build up to 2,500 lb. to hold the array's shape. Clearly, it is unreasonable to expect 2,500 lb. of horizontal holding power to be achieved by a 2,000 lb. normal force on a ball anchor. In fact, a rule of thumb for a conventional dead weight anchor is one-half pound of holding power per pound of weight. Consequently, the anchor shifts to the right. The array distorts, creating more "lift" on the anchor; the SDC cable becomes taut again, so that its lift force increases, and the anchor possibly goes back into a state of suspension.

(U) If the ship now steams shoreward while paying out additional cable the angle of the SDC force on the anchor approaches the horizontal. Finally, the array stabilizes as the weighted SDC on the ocean floor provides sufficient friction to prevent anchor motion.

(U) We believe that the preceeding narrative more-or-less describes what actually happened. Had the inshore anchor weighed enough to sustain the array's configuration by itself, initial anchor touchdown would have been identified by a corresponding reduction in tension, and implantment of the array itself would have been completed. Because there was insufficient weight to firmly moor the array immediately after the final configuration was achieved, the array was subjected to dynamic loading for a sustained period of time. Ship pitching and heaving during rough weather was translated into a forcing function for the inshore anchor by the connecting SDC cable. The motion of the as-yet suspended anchor was resisted by the array itself, primarily at the lower end of the inshore leg.

(U) It is possible that a healthy cable would have survived the aforementioned lower leg dynamic stresses, but as has already been mentioned, the cable had been substantially weakened by this time.

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*The inshore anchor weight of 3,000 lb. and the 45 ft. of chain weighing 1,000 lb. are all taken as part of a lumped mass.

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(U) All other aspects of the implantment plan appear to have been in order. Implantment calculations, described in Appendix C, were sufficiently accurate and extensive, except for the case cited above.

4.7 Influence of the Operational Plan

(U) There were three factors influencing failure which were not directly due to either the array cable or to the implantment plan:

  (1) Irreversibility of the payout process. The use of glass spheres to render the cable neutrally buoyant and a stern chute in payout made reversal of payout almost impossible. Lack of provision for cable haul-in proved to be a deficiency which led to blanking out of the entire outboard leg. Recall that the electrical short appeared after 13,000 ft. of that leg had already been payed out and that its location was disgnosed to be 11,000 ft. below the payout point. Had the payout process been reversible, that leg would have been hauled back in for repair as soon as the short was discovered.

  Reversibility could have been achieved by use of built in buoyancy elements and by payout of cable directly from reels. If constraints due to time, cost, availability or technology deficiencies rules out both built-in buoyancy elements and reels, then reversibility could at least have been facilitated if the stern plate had been more rounded at the bottom and had rollers to enable the array cable with attached spheres and instrument cages to slide up.

  (2) Ship motion. The NAUBUC maintained excellent positional control throughout the emplantment. Its 4 bow thrusters as well as the navigation system made it an ideal vessel for the task from the standpoint of implantment configuration accuracy. However, the heaving, pitching and rolling motions of the ship were excessive at several stages of the implantment. During lowering of the offshore leg, ship motion caused the tension at payout to fluctuate between 3,000 and 14,000 lbs. The resultant dynamic stresses undoubtedly aggravated the cable's electrical integrity at the

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hockle where the short occurred. Ship motion also influenced the decision not to haul back cable for repair of the leg nor to make the electrical dead-end at the point of identification and not lose the instrumentation output on the remainder of that leg.

During lowering of the inshore anchor the weather go so rough that the ship was rolling up to 30°. As a result of this motion, tension at payout ranged from 3,600 to 9,000 lbs. The excessive ship motion also had some influence on failure of the inshore anchor as planned and was directly responsible for the decision not to make the final weighted chain attachment.

Obviously, the ship motion was not within tolerable limits. A much larger ship would have been more suitable because of reduced sensitivity to wave-induced motion.

(3) Weather. The weather was much worse than what the operation could really tolerate. As mentioned previously, the inertia of a larger ship than the NAUBUC would have resisted wave forces with less resultant motion. The implantment was orginally scheduled for late August, a period for which weather forecasts were more favorable. Based on technical considerations alone, the implantment should not have been carried out in December with the NAUBUC.

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5.0 RECOMMENDED RECOVERY PROCEDURE

5.1 General Discussion

(U) In view of the severe twists known to be in the cable as well as evidence of further damage at the electrical shorts, it appears that the structural integrity of each inclined array leg has been reduced substantially. This possibility must be considered in the recommendation of retrieval procedures.

(U) The NAUBUC is not a suitable ship for cable recovery. The radius plate at its stern is at best suitable for payout only. Haul-in of cable under several thousand pounds tension over the stern chute is just not desirable, even if the glass spheres are removed before reaching it. Furthermore, the drum and fleeting knives aboard the NAUBUC will not be able to accommodate the stress-relieved segments very well. If the fleeting knives truly twist the cable as deduced in Section 4.3, then a multitude of hockles would form as it approached the machinery. Finally, the small size of the NAUBUC will render it vulnerable to spurious motions during attempted array retrieval, with corresponding dynamic cable tensions.

(U) Recovery should be made on powered reels having at least a 12 ft. diameter -- the larger the diameter, the better. If the reels themselves do not hang over the end of the recovery ship, then preliminary cable contact should be made with rollers, not with a stern plate.

5.2 Recovery from the Offshore End

(U) If the retrieval process were to begin with pull-up of grapnel line at the offshore end and then proceed shoreward towards the array cable as shown in Figure 9, then, because of the 2,500 lb. buoys, the array offshore leg recovery tensions would be substantially lower than those encountered during payout. Likewise, the horizontal leg, which never got into much difficulty during implantment, will hardly be stressed during haul-in. In fact, the problem which may occur with the horizontal leg is "looping" of the cable due to the relief of all tension. Trouble will take place, however, when the inshore array leg is hauled in. Let us see why.
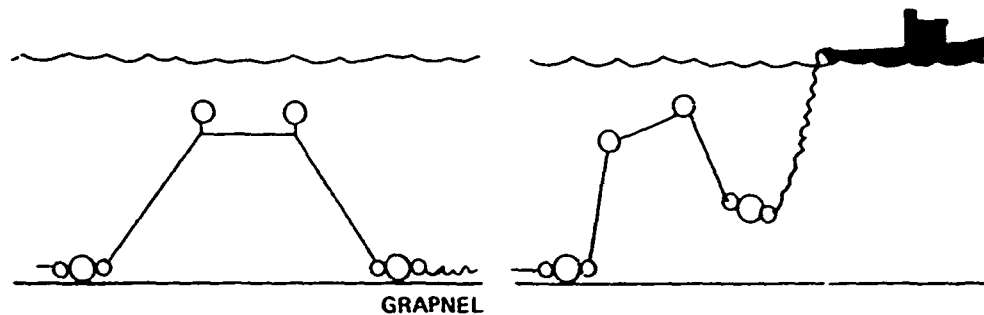
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FIGURE 9. RETRIEVAL OF OFFSHORE LEG

(U) Under "optimum" positioning, the inshore leg will be vertical when the anchor is first pulled (Figure 9).   The ship will then proceed shoreward
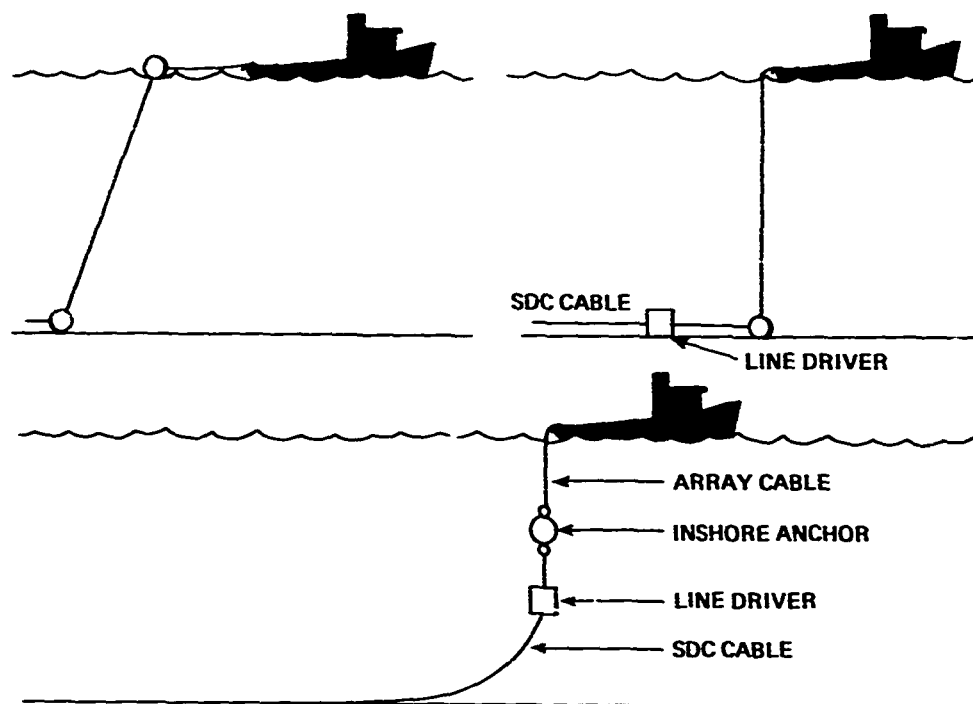
FIGURE 10.   RETRIEVAL OF INSHORE LEG

at a speed which keeps this line vertical under subsequent haul-in. Static tensions for the inshore leg (neglecting drag forces) will be determined by

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the combined weights of the anchor, the line driver and the suspended portion of SDC cable. If the latter were perfectly flexible 14,400 ft. of it would be suspended just before anchor haul-in. The total load on the array cable would be 4,000 + 300 + 0.317 x 14,400, a total of 8,900 lbs. Actually the bending stiffness of the SDC cable will prevent it from dropping down vertically. It will slope down somewhat, thereby increasing the load required to haul in the cable. In addition there may be difficulty positioning the recovery ship at the optimum location.

(U) Therefore, let us assume the static load on the array cable is 10,000 lbs. Dynamic amplification factors as high as 2 were encountered during implantment. If this were the case for retrieval, the tensions may go up to 20,000 lbs. Considering the already-weakened condition of the cable, attempted retrieval in this manner certainly would run the risk of breaking it. Nevertheless, we can take our chances and try to pull up the inshore leg. However, even if successful we might not be able to inspect this leg meaningfully if excessive tensions change the appearance of the existing fault or create additional faults.

(U) If the array cable breaks while the inshore anchor is suspended, then the remaining assembly would fall to the ocean bottom. Subsequent retrieval attempts could be difficult because of possible entanglement, etc. If the array cable does not break, then the logical alternatives after the line driver is on board are as follows:

(1) Repair the array as required and pay it out again, only this time in an offshore direction.

(2) Attach another array to the line driver and implant it, again in an offshore direction.

(3) Reposition the end of the SDC cable after preparing it for array attachment at a latter time. For example, attach a long length of grapnel followed by a small anchor or some weighted chain.

(4) Haul in the SDC cable. This decision would be based on the conclusion that the cable is not useful for future efforts in its present position.

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5.3 Recovery from the Inshore End

(U) Retrieval from the inshore end with minimal risk of damage to the SDC should begin with grappling close to shore where some slack exists (Figure 11). After cutting this cable on deck, SDC haul-in from the inshore direction commences.
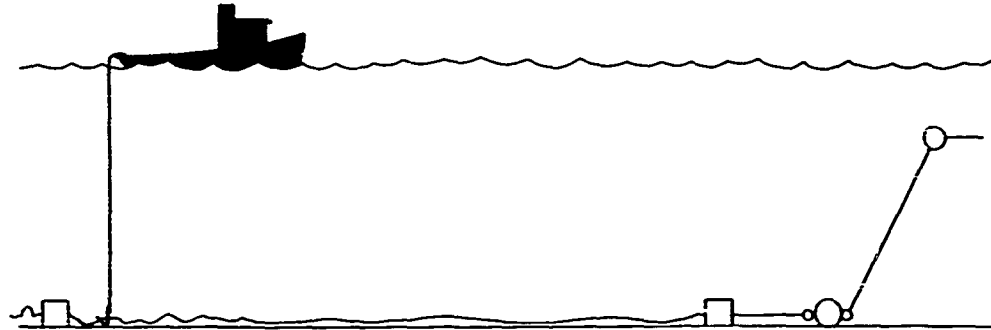

FIGURE 11. RETRIEVAL FROM INSHORE END

Retrieval continues in this direction till the entire array is aboard ship.

(U) The primary objection to this procedure is the additional effort in recovering all that SDC cable, especially if its present location is a useful one for some future effort. A second shortcoming is the excessive tension in the SDC during inshore anchor recovery. Referring to Figure 12, we observe
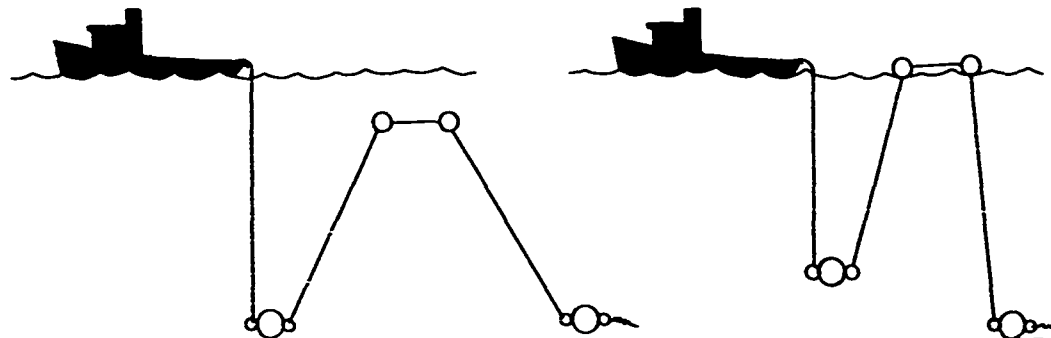

FIGURE 12. RETRIEVAL FROM INSHORE END (CONTINUED)

that the highest tension in the SDC occurs just as the anchor is pulled up. Assume the ship is positioned directly above the anchor so the weight to be lifted is $300 + 4,000 - 2,500 + 0.317 \times 14,400 = 6,400$ lbs, plus additional

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jerk required to pull the anchor out of its imbeddment. This last force need not be included if we use a dynamic load factor of 2. Therefore, the maximum load on the SDC will not exceed 12,800 lbs. which is well within its rated breaking strength of 18,000 lbs. Whereas the condition of the SDC is believed to be good, there is a probability of retrieving all of it without a mishap.

(U) The inshore leg can now be recovered under a very nominal range of tension -- 4,000 lbs. dropping to zero, which is important in view of its weakened condition. The horizontal leg likewise can be hauled in without any difficulty. However, tensions on the offshore leg will be considerably higher. Referring to Figure 13, we observe that the greatest static tension will occur just before the offshore anchor is retrieved, where its weight in air plus
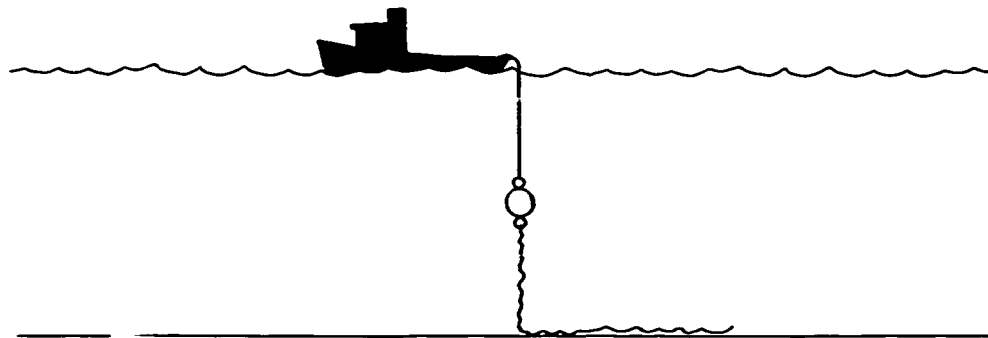

FIGURE 13. TENSIONS ON OFFSHORE LEG DURING RETRIEVAL

the weight of 14,400 feet of grapnel line must be carried. Thus, the maximum static load is 7,000 + .125 x 14,400, a total of 8,800 pounds. With a dynamic amplification factor of 2, we get possible tensions of 17,600 pounds. If the cable has been weakened substantially then breakage is possible. If it breaks, we can then recover the broken piece by grappling for it from the outboard end via the stable braid. In any case, diagnostic efforts might be difficult as a result of the high tensions encountered.

5.4 Alternate Recovery Procedures

(U) The following variations of the method described in Section 5.3 are possible:

> (1) Same as in Section (5.3) except cut the cable just before the offshore buoy is reached. Then recover the offshore leg by

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grappling for the stable braid. This way tensions in the offshore leg will be minimal and diagnostics of that leg can be carried out.

The only objection to this method is the possibility of entanglement of the suspended "loop" of array cable sometime after the inshore anchor is lifted.

(2) Same as (1) except replace the buoy with a nominal weight and lowering line. Lay the offshore leg on the ocean floor using this lowering line and then grapple for the leg from the other end.

The intricate procedure described is only worthwhile if it is considered vital to diagnose the state of the offshore leg.

(3) Grapple for that portion of array cable lying between the inshore anchor and the line driver (Figure 14). If successful, cut the cable on deck, attach grapnel to the shoreward end for future splicing. Then proceed as described in Section 5.3. If the cable breaks before
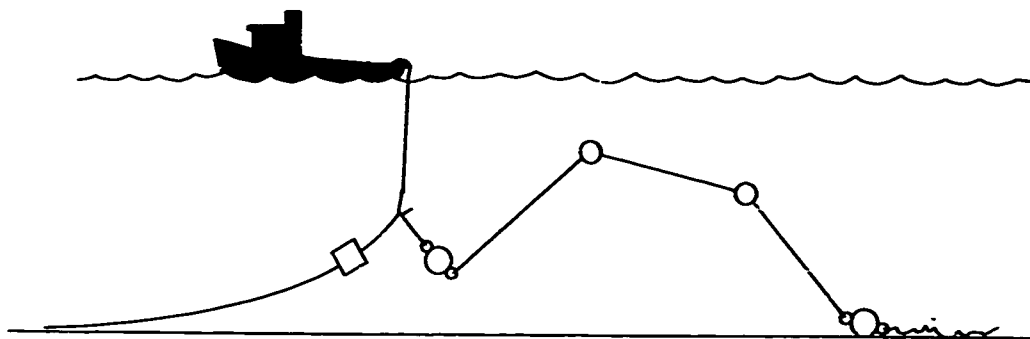

FIGURE 14. RETRIEVAL AT LINE DRIVER

reaching the ship, then proceed to the offshore end for retrieval from that direction.

This method is appealing in two ways: Successful grappling results in all the advantages of inshore end recovery (except for possible damage to the very end of the SDC)

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and still leaves the SDC intact. Cable severance in an unsuccessful grappling effort means recovery from the offshore end described in Section 5.2, only with no significant stressing of the inshore leg.

5.5 Conclusions

(U) Obviously, array retrieval from the inshore end makes no sense if the present SDC location is useful for future implantments. For this case recovery should be from the offshore end unless accurate diagnostics of the offshore array leg are top priority. In this latter case method (3) of Section 5.4 should be used.

(U) If the present SDC location is of no further use, then retrieval from the offshore end still has the most appeal if diagnostics of the inshore leg are not deemed to be important. Otherwise retrieval should be outward, starting at the SDC cable splice.

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6.0 RECOMMENDATIONS FOR FUTURE EFFORTS

(U) This section indicates possible improvements which are mostly within the scope of the present effort and which all pertain to the array cable directly.

(1) Glass spheres. Buoyancy elements, if used in the future, should be incorporated into the cable itself rather than have separate elements which are fastened on deck. This modification would speed up cable payout, and haul-in, if necessary.

(2) Monitoring of cable twisting. There was no way of knowing how much the cable had been twisted. A white line painted on the cable during final reeling at the manufacturer's plant would provide visual evidence of any subsequent cable twisting.

(3) Tolerances on stresses for electrical and structural integrity. Values should be established for tension, bending, torsion (right-handed and left-handed), traction, and the combined loadings discussed previously.

(4) Use of 12' drum, fleeting knives and DOHB. If cable is going to be payed out from a coiled configuration in the future, an alternative system of payout machinery should be considered -- one which does not put twists into the cable.

(5) Neutral buoyancy. The principal arguments for neutral buoyancy are weightlessness during implantment and straight line configuration in the absence of currents. Cables with positive weight in water can provide some of the necessary anchoring forces while cables having negative weight can provide buoyant forces, and the static configuration of positive or negative weighted cables, although not straight lines, can be calculated with as much accuracy as for neutrally buoyant cables. The two sketches in Figure 15

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give examples of how weighted or buoyant cable can help
the implantment process.
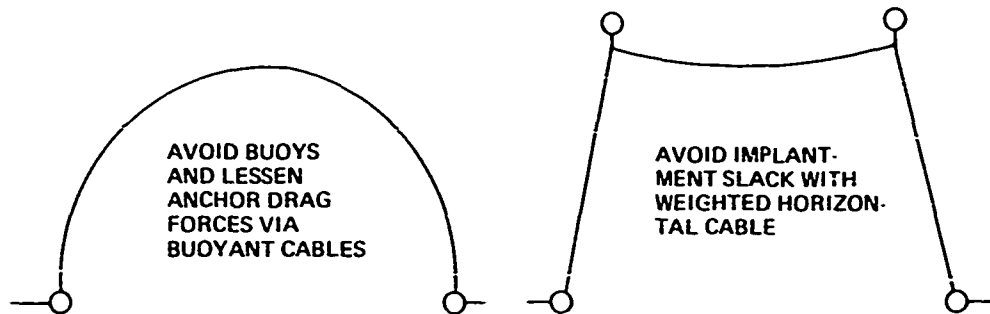

FIGURE 15. USE OF POSITIVE AND NEGATIVE BUOYANCY CABLES

(6) Instrument packages. The instrument cages weighed several
hundred pounds, were not flexible, were clumsy at best go-
ing through the machinery, provided a drag profile of 5" as
opposed to 0.68" for the rest of the cable and, in combina-
tion with the splice rods, were accumulation points of
twisting. Miniaturization of the packages would alleviate
all of the above-mentioned problems. Even better would be
a plug-in electronics system which could be readily attached
on deck as cable was being payed out. In either case, in-
plantment speed, implantment facility, and reliability would
be improved.

(7) Torque relief. The cable should have joints every hundred
feet, say, to relieve torque that unavoidably has gotten
into the cable. If such joints are not within the state of
the art for deep sea applications, development efforts would
be worthwhile.

(8) Cable handling. The cable should be handled as little as
possible. For example, it might have been possible to com-
pletely eliminate the 20 ft. tank at the array fabrication

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site by performing all the flooding operations in the modified truck flatbed.

(9) Coiling. It is obvious that handling of cable on reels is preferable to coiling. Future implantment efforts should provide for handling of cable exclusively on reels, if possible.

(10) Anchors. Whatever the configuration desired, anchors should be able to provide their designated horizontal holding power upon touchdown, without any subsequent dragging.

(11) Radius plate. The radius plate at the stern of the NAUBUC should be replaced by a pulley of equal radius or by rollers. Whichever is used should also serve as a dynamometer. The dynamometer on the NAUBUC was not at the stern, but at the machinery exit. It gave readings about 30 percent too low during payout and about 30 percent too high during loading of the cable aboard the ship.

(12) Reversibility of payout procedure. The Test Bed implantment was, for all practical purposes, irreversible. Action on items (1), (4), (6), (7), (9) and (11) as suggested would make the payout process reversible for purposes of making repairs or for future retrieval.

(13) Slack cable. Relieving a cable entirely of several thousand pounds tension all at once, as was done with offshore anchor touchdown on the Test Bed, is asking for trouble. The implantment plan should not permit this occurrence. For example, had the Test Bed offshore buoy been attached to the array 1,000 ft. sooner (Figure 16), then it would have submerged before the offshore anchor touched down, and the entire offshore leg would have remained under considerable tension (about 3,500 lbs.) after touchdown.
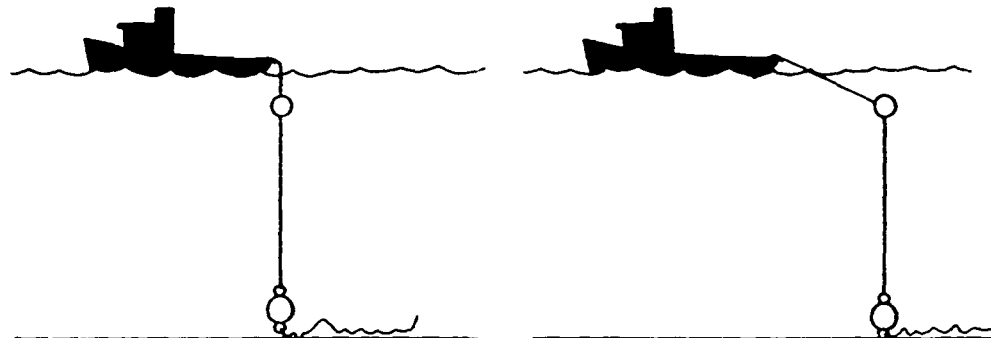
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FIGURE 16.   PLAN TO AVOID TORQUING

(14) Cable mechanical properties. Armored cable is <u>not</u> a classical linear elastic material. It twists under a pure tensile force; its response to a left hand torque is different than that due to a right hand torque; it exhibits hysteresis loops under cyclic loading; it coils "naturally" in only one direction; it requires many cycles of prestressing in order to take out the constructional slack, etc., etc. Unless one is willing to accept a high risk of implantment failure, the cable handling and loading procedures must be known, and the cable's response to these procedures must be predictable. This was hardly the case for the Test Bed. In the future, a prototype cable should be subjected to the same history of handling as the actual cable. One must keep in mind that the array cable is "the" structure, and moreover, is a non-redundant one. Failure of any part of the cable means failure of the entire Test Bed.

(15) Retrieval of array. Future arrays must be so <u>designed</u> that there should be no difficulty in retrieving them for repair, for inspection, for deployment to another site, for for salvage. Section 5 describes the difficulties in attempting to retrieve this Test Bed.

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(16) Proper cable. The cable's properties must be compatible with its handling. If constraints do not allow "optimum" handling of the cable, then perhaps another cable might be more suitable for this particular process. For example, if the NAUBUC's payout machinery had to be used, a cable that could "take" the twist was required.

(17) "Freezing" the implantment. It should be possible to freeze the partially implanted array in a "safe" configuration while riding out a storm or an intolerably high sea state. Achievement of a safe configuration might require attachment of a sub-surface buoy, or of several buoys, for example. Possibly the implantment procedure should be structured so that no stage of the operation is more than, say, 1/2 hour away from a "safe" configuration, either through additional payout, haul-in, buoy attachment, or a combination of these. An example of a safe configuration is illustrated in Figure 17.
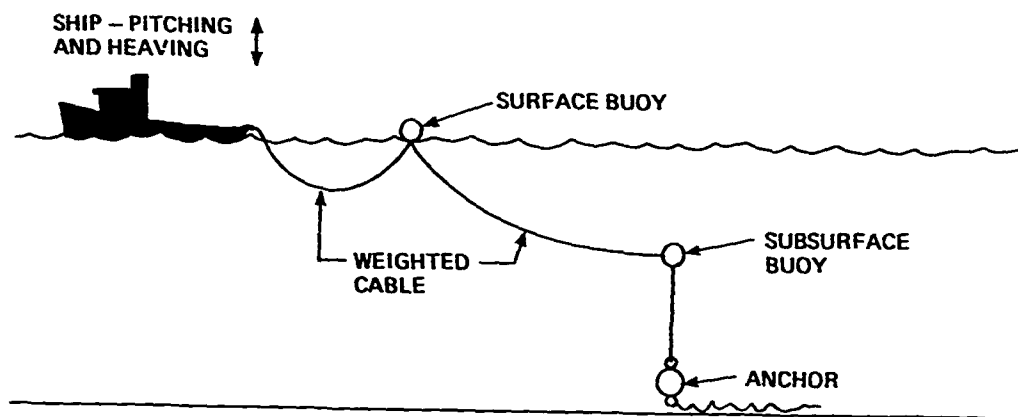

FIGURE 17. FREEZING THE IMPLANTMENT

(18) Alternative array platforms. Rigid truss-type structures, for example, should be considered, and tradeoff studies among such alternatives should be made.

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(19) Ship size. The NAUBUC was too small for this particular implantment. A much larger ship, being less prone to wave-induced motion, would be more suitable for future implantments.

(20) Cable entanglement. Lowering of a weight by two cables (as was the case for the inshore anchor of the Test Bed) can easily lead to entanglement unless the cables are perfectly torque-balanced. The chances of a 20,000 ft. length of cable being perfectly torque-balanced, even if designed as such, are so small that future implantments should not call for such lowering procedures unless prototype experimental evidence of no entanglement has been ascertained.

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REFERENCES

1. "LRAP Test Bed (U)," TRW report to ONR, 15 July 1970, Contract No. 14147-W451, SECRET.

2. "LRAPP Engineering Test Bed Program (U)," ONR Code 485, 15 July 1970, SECRET.

3. "Technical Plan for the Implantment of the Test Bed Array for the LRAPP Program (U)," NUSC, New London, 10 August 1970, CONFIDENTIAL.

4. "Test Bed Notebook," Vols. 1 and 2, M.M. Balaban, notes from interviews with individuals listed on page 44.

5. "Preliminary Report on the Status of the LRAPP Test Bed Project," 11 January 1971, by J.B. Gregory, ONR Code 485.

6. "LRAPP Array Implantment Log," notes of H. Tremmer.

7. "Submarine Cable Mechanics and Recommended Laying Procedures," by C.E. Roden, Bell Telphone Laboratories, 1964.

8. "A Survey of Publications on Mechanical Cables and Cable Systems" by P. A. Laura and M.J. Casarella, Catholic University, Washington, D. C., 1968.

9. "A Survey of Publications on Mechanical Wire Rope and Wire Rope Systems," by H.H. Vanderveldt and R. deYoung, Catholic University, Washington, D.C., 1970.

10. "Cable Systems Under Hydrodynamic Loading," by M.J. Casarella and M. Parsons, Catholic University, Washington, D.C., July-August, 1970.

11. "A New Design Criterion for Wire Rope," by D.C. Drucker and H. Tachan, ASME Journal of Applied Mechanics, March, 1945.

12. "Mechanical Behavior of Stranded Wire Rope," by P.A.Laura, et. al., MTS Journal, May/June 1970.

13. "Why Wire Rope Breaks and How to Prevent It," by L. Chase, Ocean Industry, May, 1969.

14. "Selecting Wire Rope for Oceanographic Applications," by F. Stavsto, Undersea Technology, February, 1967.

15. "Deep Sea Mooring Cables," by P.B. Stimson, Transactions of the 2nd International Buoy Symposium, Washington, D.C., 1967.

16. "Buoy Mooring Cables, Past, Present and Future," by W.S. Richardson, Transactions of the 2nd International Buoy Symposium, Washington, D.C., 1967.

17. "A Study of the Causes of Wire Rope and Cable Failures in Oceanographic Service," All-American Engineering Company, Wilmington, Del., September, 1967, AD 658871.

18. "Investigation of Wire Rope Service Requirements and Design Parameters," Battelle Memorial Institute, Long Beach, Calif., August, 1969, AD 709471

UNCLASSIFIED

UNCLASSIFIED

19. "Mooring Motion," by N.P. Fofonoff et.al., WHOI, May, 1968, AD 669456.

20. "Experimental Evidence on the Modes and Probable Causes of a Deep-Sea Buoy Mooring Line Failure," by H.O. Berteaux et. al., A Critical Look at Marine Technology, MTS, Washington, D.C., July, 1968.

21. "Torque-Balanced Wire Rope and Armored Cables," by K.W. McLoad and W.E. Bowers, Transactions of the 1964 Buoy Technology Symposium, MTS, 1967.

22. "Handbook of Ocean and Underwater Engineering," ed. by J.J. Myers, et. al., Section 5: "Underwater Cables".

23. Rochester Corporation data sheets of 7 June 1970. Transmitted by W.E. Garne.

24. "Cable, Underwater Double-Armo d Coaxial," Specification No. NUSL-C-2321/2031-150, 30 January, 1970.

25. Letter dated 24 September 1970 from U.S. Naval Regional Procurement Office, Philadelphia, to the Rochester Corporation.

26. Letter of 28 April 1970 from John V. Burnett, Rochester Corporation, to Rick Swenson, Code 2212, NUSC.

27. Preformed Line Products Company letter of 22 May 1969 to the Rochester Corporation, Culpeper, Virginia.

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PERSONS INTERVIEWED IN REFERENCE 4:

Gene Bissett, NUSC, New London

Tom Cummings, NUSC, New London

Gary Griffen, NUSC, New London

Bob Pierce, NUSC, New London

Ray Smith, NUSC, New London

Rick Swenson, NUSC, New London

Walt Whittaker, NUSC, New London

Bob Welsh, NUSC, New London

Bob Rumpf, NUSL, Tudor Hill

John Gregory, ONR

Al White, ONR

Jim Catlow, NOL, Ft. Lauderdale (telephone)

Townley Wolf, OSI, Reston

Rodney Lawrence, WECO, Winston-Salem

Carl Holm, Global Oceanics, Miami Beach

Alvin Crane, Rochester Corporation, Culpeper, Va.

Ernie Garne, Rochester Corporation, Culpeper, Va.

Stan Leavitt, Rochester Corporation, Culpeper, Va.

T. I. Martin, Rochester Corporation, Culpeper, Va.

Steve King, deBell and Richardson, Hazardville, Conn.

Roland Trudeau, deBell and Richardson, Hazardville, Conn.

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APPENDIX A

NOMENCLATURE

(U) The words cable and wire rope are often used synonymously. In what follows we will think of wire rope as purely a strength member and of cable as primarily an electrical conductor whose mechanical properties may or may not be significant, depending on how it is used.

(U) The word "twist" is often used interchangeably to describe both a twisting force and a twisting effect. This can be done without ambiguity for classical elastic materials, where there is a one-to-one relationship between the two phenomena. However, cables have a propensity to undergo twisting motion when subjected to pure tension in the absence of any twisting forces.

(U) Therefore, in order to keep the discussion free from ambiguity, the word twist as used here refers strictly to motion while the word torque is used to describe a twisting moment. The word torquing, on the other hand, is used to describe a cable's desire to twist under a pure tensile force or to build up torque under a pure axial elongation. A cable will be called torque-balanced if its torquing tendancies are negligible.

(U) The words limp and rigid are used in a strictly descriptive manner to characterize a cable's resistance to twisting when subjected to a torque. The words flexible and stiff are reserved for characterizing a cable's tending compliance. Of course, flexibility and limpness usually go hand-in-hand as do rigidity and stiffness, but the words are used here only in the strict sense indicated in order to avoid ambiguity.

(U) The outer winding of armor on the LRAPP Test Bed cable has a right hand lay, as shown in Figure A.1, so the words right hand twist and left hand twist
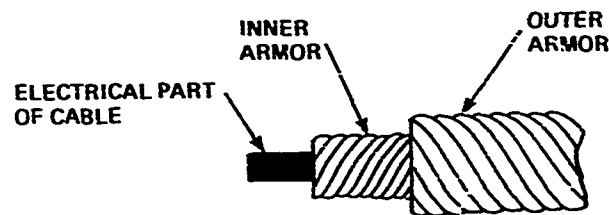
INNER
ARMOR

OUTER
ARMOR

ELECTRICAL PART
OF CABLE

FIGURE A.1   DOUBLE ARMORED CABLE

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refer to directions which tend to <u>tighten</u> the outer armor and <u>loosen</u> the outer armor, respectively.

(U)   Finally, the words rotation or turn imply a change in direction -- no more, no less.   A rotation may be associated with a twist or it may be a rigid body rotation.

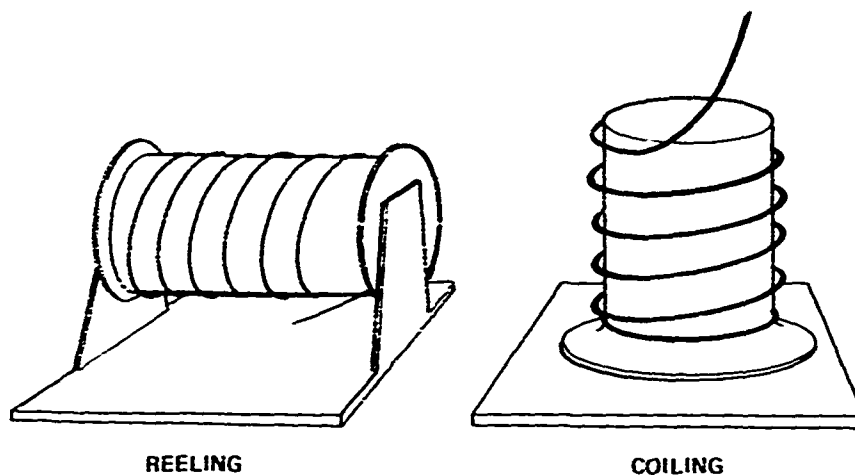(U)   Let us now distinguish reeling from coiling:

REELING   COILING

FIGURE A.2   REELING AND COILING

<u>Reeling</u> is pure bending, while <u>coiling</u> is a combination of bending and twisting. The direction of reeling is <u>circumferential</u>.   The ultimate direction of coiling is <u>axial</u>.   The difference is shown in Figure A.2.   Likewise, cable on a reel may be <u>unreeled</u>, i.e., pulled off circumferentially, or it may be <u>uncoiled</u> (pulled off axially).   The difference in the two effects may be observed by removing motion picture film from a reel by each of the two processes.   Of course, the word "coil" does not necessarily imply a reel.   Cable, for example, can be

coiled within the confines of a tank. Very limp cable can be coiled on just plain ground.

(U) The direction of coiling or uncoiling will be denoted as <u>clockwise</u> if the touchdown point of the cable follows a clockwise path when the observer looks <u>down</u> at the process. The reference direction for counterclockwise coiling or uncoiling will also be <u>down</u>. As an example, the cable in the right hand side of the last diagram is either being coiled counterclockwise or uncoiled clockwise. Note that cable coiled clockwise will be uncoiled counterclockwise (assuming the final end coiled is the initial length uncoiled), and vice versa.

(U) Consider now a length of cable which is initially straight and untwisted. If the cable is reeled, it will remain untwisted* on the reel. However, if this cable were coiled, then twist would indeed develop. If the cable were coiled counterclockwise as shown in the last diagram on the right, it would acquire a left hand twist of 360° for each circumference created, tending to loosen the outer armor of right hand lay cable. Of course, the twist would be taken out of the cable as it was subsequently uncoiled clockwise.** Likewise, coiling the same cable clockwise produces a right hand twist which tightens the outer armor.

(U) Cable which does not exhibit hysteresis effects under the loading will be torque-free after uncoiling if it was torque-free before coiling. On the other hand, cyclic twisting and untwisting of a cable which does exhibit hysteresis may produce a residual torque if pulled taut, or residual loops if allowed to hand free.

(U) Finally, we note that the torque-twist relationship of a cable in the left hand direction is <u>not</u> necessarily the same as its rigidity in the right hand direction. This property as well as several others make it very inaccurate to regard cable as a linear elastic material.

(U) We define <u>looping</u> in the usual way. Relatively stiff cable which is slack will form loops if twisted sufficiently. Usage of this term is restricted to loops which disappear upon removal of load.

---

*Provided that the cable is torque-balanced under the reeling tension.
**Assuming no severe distortions nor hysteresis effects.

(U) We define birdcaging as the visual effect of an excessive left hand torque on right hand outer armor (and vice versa). The outer armor tends to spread out radially, giving the appearance of a birdcage (hence, the name) while the inner left hand lay armor tightens. Birdcaging usually entails an inelastic deformation of cable wires.

(U) We define a hockle as the visual effect of an excessive right hand torque on right hand outer armor, and vice versa. The inner armor wants to spread out radially while the outer armor wants to tighten further. The result is a series of clusters and separations of outer armor with the inner armor tending to birdcage at the separations. A hockle always contains deformations of wire beyond their elastic limit, i.e., it is an irreversible phenomenon. It often damages the cable electrically as well.

(U) Finally we define a kink as a visual discontinuity in cable direction. A kink can result from pulling on a hockle, or more commonly, from jerking a loop. It is accompanied by severe distortions, cusps of wire, possible broken strands, and an electrical break or short.

(U) A birdcage limits the structural capabilities of the cable to those of the inner armor. A hockle limits the capabilities to the partially weakened outer armor. A kink, on the other hand, makes the cable totally unreliable as a structural member.

(U) Terms used in the body of this report will have the unique meanings given in this Appendix.

APPENDIX B

ARRAY CABLE MANUFACTURE

(U) The array cable was manufactured by the Rochester Corporation at
Culpeper, Virginia. It is double armored, has a diameter of 0.680" and has their
designation #20680. The armor is galvanized improved plow steel -- the outer
lay consists of 36-.050" wires helically wound in a right hand direction,* while
the inner lay contains 22-.065" wires having a left hand* winding. The armor
surrounds the electrical part of the cable which is coaxial with polyethelene
insulation. Additional dimensional information on this cable may be found on
the Rochester product sheet which is reproduced on the next two pages.**

(U) The cable was originally manufactured for Scripps Institute as a
highly torque-free product. The construction was modified slightly for NUSC: A
braided copper shield was used in lieu of the served shield. In addition, the
cable for Scripps was prestressed to 8000 lbs. while the Test Bed cable was not
prestressed.

(U) As a result of these minor differences, the Test Bed cable has
slightly different rotation characteristics under tension. The applicable data,
supplied by Rochester (reference [23]), is shown in Figure B.1.

(U) During the manufacturing process of the cable the individual armor
strands are each subjected to approximately 50 lbs. tension. The tension is re-
lieved somewhat as the armor compresses the electrical core radially.

(U) The cable manufactured by Rochester is usually prestressed to 40
percent of breaking strength before put on reels for shipment. This prestress
removes additional slack and provides some quality control -- cables which can't
take 40 percent of rated breaking strength are instantly discovered.

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*The angle of winding usually varies from 18°-23° with the cable axis. The
nominal angle is determined by manufacturing considerations, not by optimum
mechanical property criteria.

**The accompanying data on this sheet is for cable #20675, which was used on the
Sea Spider.

TORQUE BALANCED CABLE COMPARISON

This report is a comparison of Conventional Double Armored Cable and Double Armored Cable designed for a minimum of free end rotation under load.

SUMMARY: 20680 Cable makes only 1.85 turns per 1000' when loaded to 50% of its breaking strength compared to 51 turns per 1000' for 20675, a Conventional Double Armored Cable.

20680, using a Served Copper Shield, has less DC Shield Resistance, less Attenuation, higher Characteristic Impedance and less tendency to have Shield to Armor Dielectric failure than the 20675 cable.

20680 has much superior characteristics for free end application, such as typified by Oceanographic towing or hoisting. NOTE: 20675 Cable, of course, is excellent for its normal application where rotation is not a factor to be considered.

All tests are after 12,000 lb. factory prestressing. Values quoted from tests are not necessarily guaranteed as specification values.

CONSTRUCTION:

	Cable with Minimum Free end Rotation Stock ≒20680 (43 Ohm, ≒10 AWG Coax. Double Armored)	Conventional Double Armored Cable Stock ≒20675 (35 Ohm, ≒10 AWG Coax. Double Armored)
Conductor (Copper, Approx. ≒10 AWG)	7/.040" Bare	7/.0385" Tinned
Insulation (Polyethylene)	.090" Wall	.067" Wall
Shield (Copper, Bare)	SERVED .0253" ← Special for NUSC	BRAIDED .010"
Belt [Jacket] (Polyethylene)	.059" Wall	.059" Wall
Braid	— —	Plastic Fibers
Armor (Special Galvanized Improved Plow Steel)—1st	22/.065" ± .002"	24/.056" ± .002"
—2nd	36/.050" ± .002"	24/.071" ± .002"

ELECTRICAL CHARACTERISTICS:

Conductor DC Resistance (Ohms/1000')	1.03	1.12
Shield DC Resistance (Ohms/1000')	.62	1.12
Conductor to Shield—Insulation Resistance, Minimum (Megohms/1000')	20,000	20,000
Shield to Armor—Insulation Resistance, Minimum (Megohms/1000')	5,000	5,000
Capacitance—1 KHz (uufd/ft.)	42 (Approx.)	48 (Approx.)
Attenuation—db/1000'— 10 KHz	.17	.24
100 KHz	.54	.75
1 MHz	2.45	2.50
Impedance—Ohms 10 KHz	50.5	40
100 KHz	48.5	35
1 MHz	43.0	35

SAMPLES—Limited number of one foot samples are available upon request.

TABLE 3. SPECIFICATIONS FOR DOUBLE ARMORED CABLE

PHYSICAL CHARACTERISTICS:	Stock #20680	Stock #20675
Diameter	.680″	.670″
Weight in Air	675 lbs./1000′	665 lbs./1000′
Weight in Water	518 lbs./1000′	512 lbs./1000′
‡Breaking Strength (by test)	31,450 lbs.	34,300 lbs
‡% Elongation at: 2,000 lbs. load	.07	.15
6,000 lbs. load	.30	.39
10,000 lbs. load	.52	.62
16,000 lbs. load	.82	.92
30,000 lbs. load	2.16	
Corrosion Inhibitor	Ferrocote #5878	Ferrocote #5878

‡ Test Results—not necessarily guaranteed as specification values.

COMPARISON OF CABLE ROTATION VERSUS LOAD

Cable Rotation °/Ft.

Load Lbs.	20680**	20675
2,000	.53 ccw*	.86 cw†
4,000	.53 "	2.57 "
6,000	.27 "	4.57 "
8,000	0 "	6.57 "
10,000	.27 cw	8.53 "
12,000	.40 "	10.86 "
14,000	.40 "	13.71 "
16,000	.67 "	18.28 "
18,000	.80 "	
20,000	.93 "	
22,000	1.33 "	
24,000	1.72 "	
26,000	2.39 "	
28,000	3.32 "	
30,000	5.09 "	
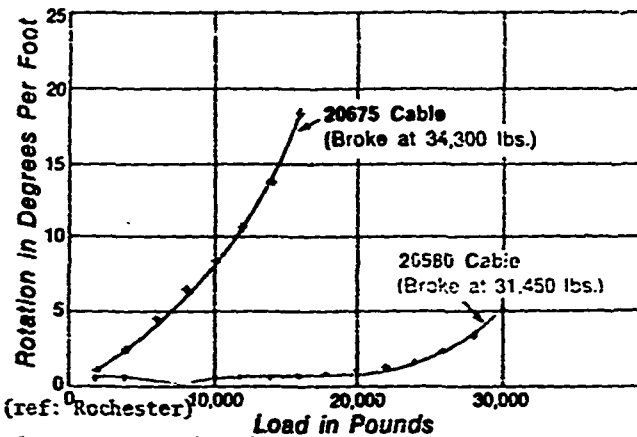
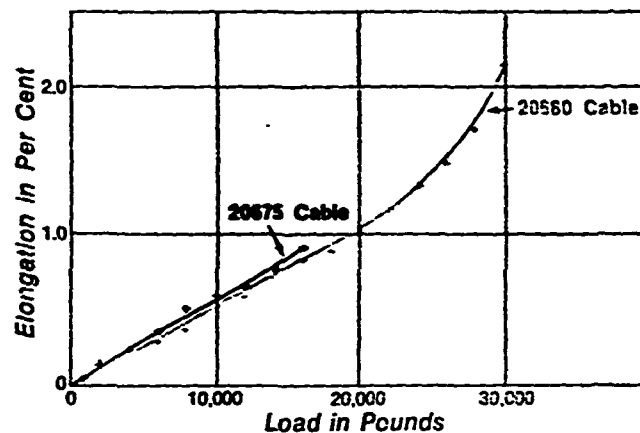† Clockwise tighten outer armor (ref: Rochester)
* Counter-clockwise
**Scripps cable. See Figure 30 for Test Bed cable data.

COMPARISON OF CABLE ELONGATION VERSUS LOAD

% Elongation

Load Lbs.	20680	20675
2,000	.07	.15
4,000	.22	.23
6,000	.30	.39
8,000	.37	.54
10,000	.52	.62
12,000	.60	.66
14,000	.74	.77
16,000	.82	.93
18,000	.89	
20,000	1.04	
22,000	1.19	
24,000	1.34	
26,000	1.49	
28,000	1.71	
30,000	2.16	

the ROCHESTER Corporation
Electro-Mechanical Division

Main Office & Factory: Culpeper, Virginia 22701
Phone: 703-825-2111

TABLE 4. SPECIFICATIONS FOR DOUBLE ARMORED CABLE
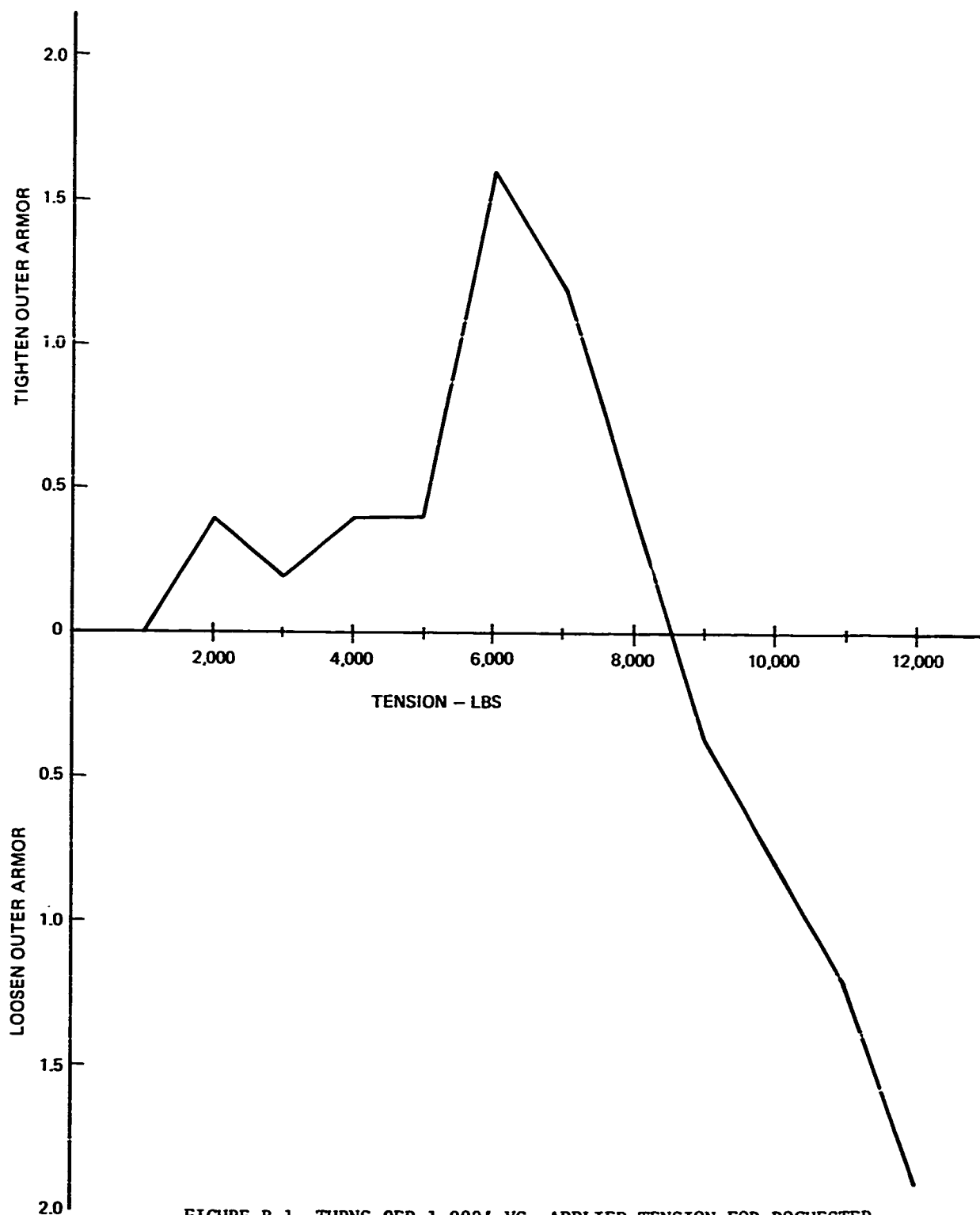
FIGURE B.1   TURNS PER 1,000' VS. APPLIED TENSION FOR ROCHESTER
DOUBLE-ARMORED 20580 CABLE

(U) Most of Rochester's cable is used in oil fields. The customer will usually prestress the cable to 40 percent of breaking strength an additional 25 times in order that it may "work itself in", before subjecting the cable to its designated usage.

(U) The rated breaking strengths of #20680 and #20675 cable are each 30,000 lbs. A prestress of 40 percent of breaking strength would require 12,000 lbs. The Sea Spider cable and the Scripps cable were each prestressed to 8000 lbs. In addition, a stripe was painted on the Sea Spider cable at prestressing in order to keep track of subsequent cable twisting. The Test Bed cable was <u>not</u> prestressed because the NUSC specification did not call for prestressing.

(U) The NUSC mechanical specifications* for the Test Bed cable can be summarized as follows:

(1) At no time during insulating and subsequent operations shall the core be subjected to a bend having a radius less than 12 inches.

(2) The breaking strength of the cable shall be at least 30,000 lbs.

(3) A reduction of the jacket diameter to 0.6 inches shall be considered a failure.

(4) At 8,000 lbs. tension the cable must not twist.

(5) At 50 percent of breaking strength the twist shall be less than 2 turns per 1000 feet.

(U) The NUSC specification was subsequently revised.** Requirements (4) and (5) were deleted and replaced with the following specification:

"At 10,000 lb. tension the maximum allowable twist is one turn per 500 ft."

(U) Rochester data, Figure (B.1), showed the revised specification was met with no difficulty.

(U) One additional remark is in order. Data provided by Preformed Products to the Rochester Corporation*** showed the #20680 Scripps cable to twist substantially more than the Rochester data shows. However, the Preformed test specimens were terminated with their own special DYNA-GRIPS which Rochester feels may have contributed to the extra rotation. Therefore, Rochester had more confidence in their own results. The Preformed data <u>was</u> made available to the customer, however.****

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*See reference [24].
**See reference [25].
***See reference [26]. **UNCLASSIFIED**
****See reference [27].

APPENDIX C

PROGRAM ENGINEERING, TESTING AND TRAINING

1. INTRODUCTION

(U) Engineering prior to the actual implantment which relates to the array cable itself consisted of:

(1) establishment of cable mechanical property qualifications

(2) preliminary testing of the array cable

(3) establishment of cable handling procedures

(4) implantment calculations

(U) Mechanical property qualifications are discussed in Appendix B. Cable handling procedures were established during the training period for the crew. The training period is described together with preliminary testing and implantment calculations in the sections which follow.

2. Array Cable Testing

(U) The array cable was tested in two ways at NUSC: The first test measured the cable's ability to sustain the dynamic load of a free-falling weight. A 6.000 lb. anchor was attached to the mid-point of a 100' length of cable. The weight was then suspended over the edge of piers by a crane as shown in Figure C.1, and the cable ends were tied down at the piers in such a manner that free fall of the anchor was possible to a depth of 36' in the water. Dynamometers were placed in the paths of the cable legs at the piers to record the tension. The crane lifted the anchor to heights up to 30'. Maximum dynamic tensions of 19,500 lbs. were achieved this way with no electrical or mechanical damage.

(U) The second test consisted of hanging a 26,000 lb. weight from the end of this same cable over the stern of the NAUBUC, paying it out and then hauling it back in. The cable broke in this manner under an apparent 22,000 lb. load* during haul-in.

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*Insufficient information about this event, as well as lack of certain controls makes any attempted correlation of cable strength with static tension values meaningless.

CRANE

←DYNAMOMETER→
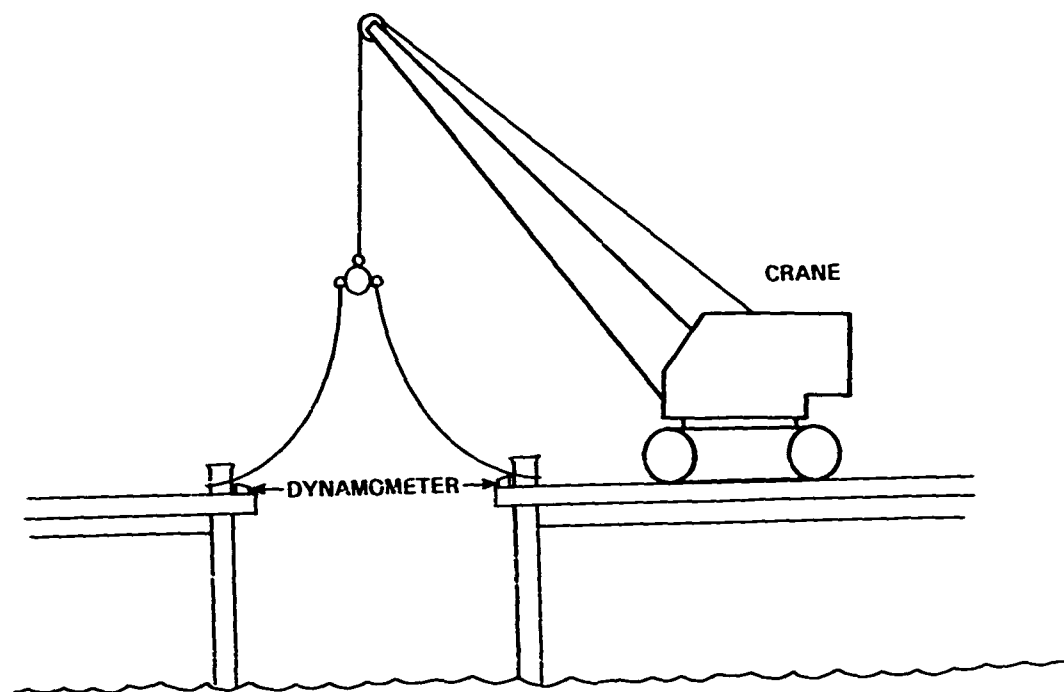
FIGURE C.1 PRELIMINARY TESTING OF ARRAY CABLE

3. Training Period

(U) The training period for the crew was planned by T. R. Cummings and CAPT. Wyeth. It included about 20 excursions.

(U) The training "array" consisted of a 1,000 lb. mushroom anchor, grapnel line (length unspecified), 11,000' of Sea Spider cable (Rochester #20675), an actual instrument cage, and glass spheres to give the cable neutral buoyancy.

(U) The crew was divided into two watches -- 6 crew members on, 6 off. The first 10 trips consisted of laying the array and recovering it, 2 cycles per trip, 5 trips per watch. The first 6 of these excursions were from NUSC to a point southeast of Block Island Sound. The crews encountered every weather condition ranging from complete calm to 4' high seas combined with 18-20 knot winds and 2 knots currents (corresponding to a sea state 3). The last 4 of these excursions were from NUSC to Gardiner's Bay, off Long Island Sound.

(U) Next, there were 4 excursions just for the bridge crews and plot teams, all out of NUSC. This was followed by a trip to Long Island Sound for the purpose of recovering an old array cable resting at the bottom of the Sound. The array was retrieved with the help of divers.

(U) Following this was a trip from NUSC to Bethlehem Shipyard, Boston, to check out the ship's machinery, from Boston to Newington where the SDC cable was loaded, and then from Newington to Boston to New London.

(U) Two more excursions out of NUSC followed, consisting of launching and recovering buoys in order to make sure they would skid off the radius plate at the stern.

(U) Finally, the remainder of the gear was loaded (minus the array cable) and the NAUBUC got towed to Bermuda where the implantment of 2 Snap-21 beacons and the Broadband Array accompanied the Test Bed effort.

(U) The only cable handling problem during training occurred on the 7th excursion. A hockle was starting to form in front of the cable machinery during haul-in. The crew straightened it out manually and it was processed through the machinery without any difficulty and without any apparent permanent damage. Another hockle then appeared behind the machinery during subsequent cable payout. It was passed through the machinery anyhow, where it appeared to have "straightened itself out".

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(U) There were no other cases of cable twisting. If anything, the train-
ing period indicated that the actual implantment would be achieved with little
or no difficulty.

4. Implantment Calculations

(U) The static implantment calculations are discussed in reference [3].
The effects of the following sources of errors on final configuration were
calculated:

    (1) Incorrect ship positioning.

    (2) Incorrect depth estimate.

    (3) Catenaries in the array resulting from lack of neutral buoyancy.

    (4) Current-induced drag forces during implantment.

(U) In addition, a dynamic analysis of the array was performed for the in-
terval between inshore anchor deployment to inshore anchor touchdown. A 6-
element lumped mass model, shown in Figure C.2 at time t = 0, was programmed for
the computer. The forces included array weight (or buoyancy) and the vector
sum of normal and tangential drag. The masses included the actual weights in
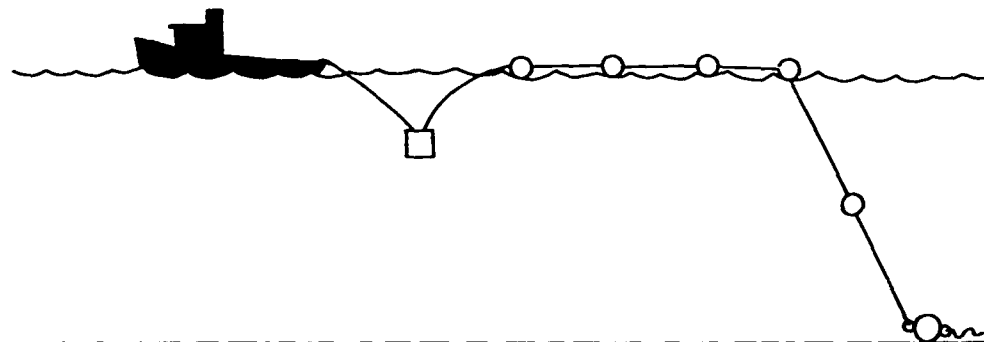water plus the virtual mass terms.

FIGURE C.2 SIX ELEMENT LUMPED MASS DYNAMIC MODEL

(U) First, the quasi-static lowering problem was run on the computer,
using a numerical integration scheme. Next, the same problem was run using a
cruder 3-element lumped mass model. Finding the resulting solutions to be with-
in 3 percent of each other, the programmers then ran the dynamic program using

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tne 3-element model. A sine wave forcing funciton of 6 ft. amplitude and 7 second period was used at the point of cable payout, representing the effect of a sea state 4.

(U) The results showed acceptable cable tensions at all stages of payout unless the sea state 4 exists during the initial time of lowering, when it is possible for the cable to go slack.

(U) Finally, the effects of currents on the implanted array were calculated. A six-element model was used (Figure C.3), and both in-plane and out-of-plane currents were inputed. Results showed no significant changes in array shape.
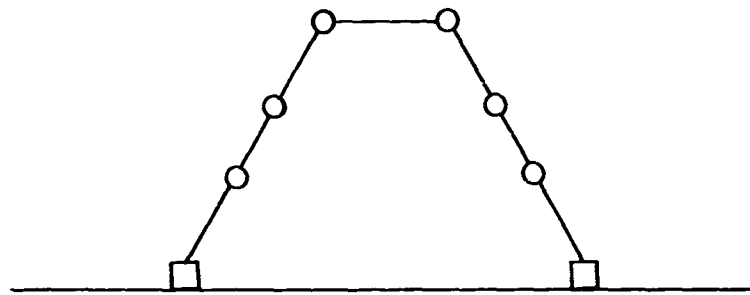
FIGURE C.3   CURRENT DRAG FORCES ON SIX ELEMENT LUMPED MASS MODEL

APPENDIX D

ARRAY CABLE ASSEMBLY AND LOADING

(U)   The array cable was shipped to the deBell and Richardson plant at
Hazardville, Connecticut in 3 reels for array assembly. Obviously, it had
been reeled under pretty high tension -- sufficient to bow the ends of the
drum. The reel diameters were each about 3 ft.

(U)   The cable was unreeled at the deBell plant and cut into prescribed
lengths as follows:

> 11 lengths less than 200' long
> 7 lengths between 200' and 1,000'
> 5 lengths between 1,000' and 2,000'
> 2 lengths between 2,000' and 3,000'
> 5 lengths between 3,000' and 4,300'

(U)   The cable segments less than 200' in length were stretched out on the
floor of the plant while the larger segments were transferred onto individual
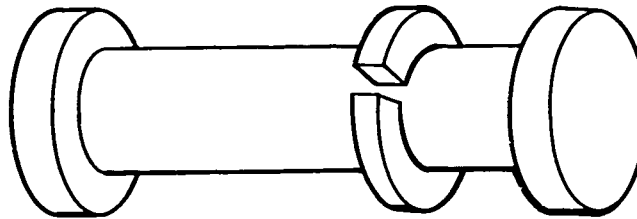2' diameter reels which were partitioned as shown in Figure D.1. By winding

FIGURE D.1   ASSEMBLY REELS

only an initial length of cable on the smaller section of reel and then switch-
ing over to the larger section, it is possible to subsequently attach connectors
to both ends while the cable is still on the reel. This was indeed done for
all the cable terminations.

(U)   The leading end of the first cable segment was connected to the line
driver, the assembly was tested electrically in a fresh water trough, and then
was unreeled out of the plant and into an annular tank whose inner and outer

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diameters are 6 ft. and 20 ft., respectively. The remaining cable on the first reel was then successively unreeled, led out of the plant and coiled into the tank. A pulley system was used to assist transfer of the cable. The minimum pulley diameter was 2 ft. Illustrations of this procedure appear in figures D.2 and D.3. These drawings were based on sketches supplied by deBell.

(U) The cable transfer was stopped as soon as all the cable was unreeled The end of the first cable segment and the beginning of the next segment were now connected to the first instrument package. The electrical connections were encapsulated in a mold and the assembly was tested electrically in a water trough.* All splices were X-rayed for electrical continuity, voids in the molds and distortions. The transfer into the tank was now resumed until the second cable segment was entirely unreeled, and so on. Eventually, all the instrument cages were connected, the assemblies tested electrically, and the entire array formed and coiled into the tank.

(U) At one particular stage of the assembly, the instrument to be connected had not yet arrived. Whereas the _next_ instrument _was_ available for installation, deBell proceeded to make _that_ connection. By this time the missing instrument had arrived. The previous connection was made and array fabrication was resumed.
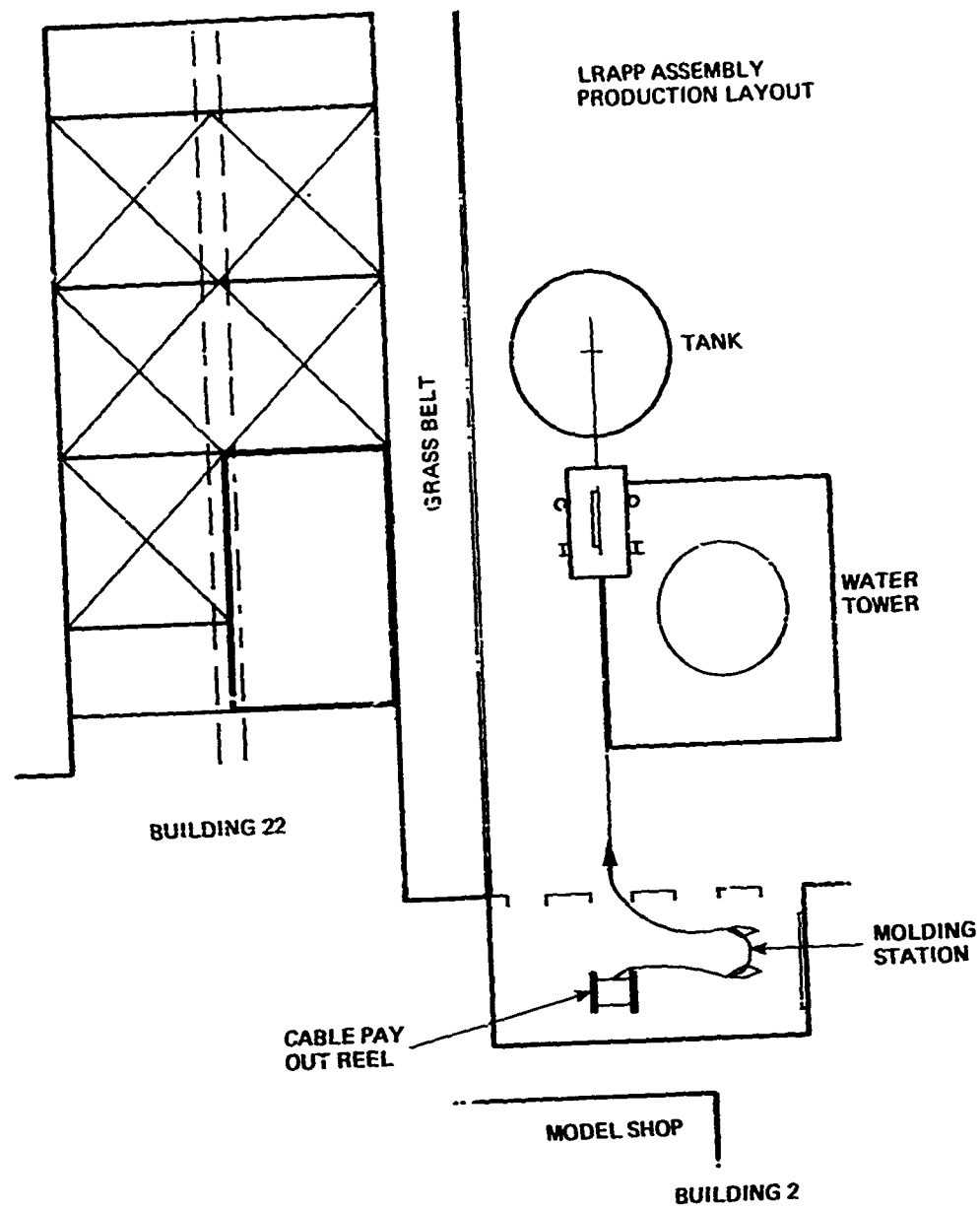
(U) In order to carry out this procedure, they first continued coiling the partial array till it was completely in the tank. Then they proceeded to coil the next segment in the tank, stopping when the cable was completely un-reeled. The new instrument package was installed, and the cable which had just been coiled in the tank was now uncoiled backwards. It was a figure eight configu-ration with an 8 ft. diameter curvature on the ground -- the minimum radius of curvature in this configuration was intended to be 5 ft. The "beginning" of this segment was eventually reached. It was dragged back into the fabrication area together with the end of the partial array. The instrument package was finally connected, molding was performed, electrical tests were made and coiling was resumed, first with cable in the figure eight configuration, and then with cable from the reel.

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*The instrument packages themselves had been pressure-tested previously. Units on the horizontal leg were tested for pressures corresponding to 11,000' depth while those on the inclined legs were tested for pressures corresponding to 16,000' water depth. Finally, all electrical cans were tested for leakage at 14 psi internal pressure.

LRAPP ASSEMBLY
PRODUCTION LAYOUT

TANK

WATER
TOWER

GRASS BELT

BUILDING 22

MOLDING
STATION

CABLE PAY
OUT REEL

MODEL SHOP

BUILDING 2

SCALE 1" = 20'

FIGURE D.2   INITIAL ARRAY ASSEMBLY
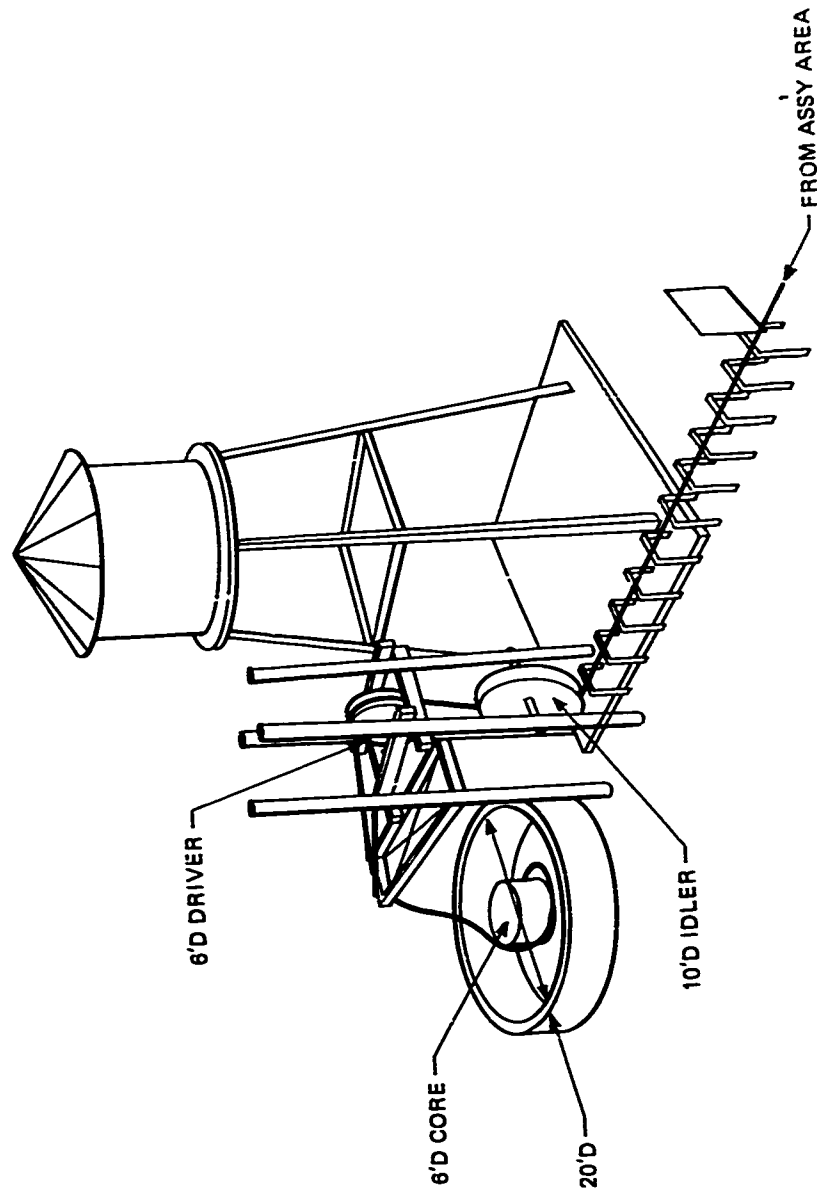
FIGURE D.3 COILING THE CABLE INTO A TANK AFTER ASSEMBLY

6'D DRIVER

6'D CORE

20'D

10'D IDLER

FROM ASSY AREA

(U) The deBell personnel think this procedure was followed 2 or 3 times. There is nothing in writing which indicates how many times or at what locations on the array this occurred.

(U) At this point, two observations are worth noting. First, the cable segments of less than 200 ft. which were laid out on the floor showed no signs of looping or "jumping". They laid down perfectly straight and flat. This would indicate that there was no torque stored in the cable while it was on the reel, either as a result of manufacture or from tensioning onto the reel. In other words, cable coming off the reel had no observable twist.

(U) Second, there were positively no twists put into the cable ends at the sockets (ref: deBell). In fact the sockets were free to rotate till they were fixed in their "natural" position.

(U) From this we can assume that the array cable had little or no twist coming out of the deBell fabrication area and going into the tank.

(U) Whereas deBell had previously coiled SDC cable clockwise without any difficulties, they attempted to lay the array cable in the tank clockwise. The first 600 ft. of cable coiled very easily, but then the going got rough -- the cable started springing up in the tank and was gradually building up a torque which was resisting further coiling (note that clockwise coiling tends to tighten the outer right hand lay armor of the array cable, while counterclockwise coiling tends to tighten the inner left hand lay while initiating "birdcaging" in the outer lay). DeBell then called a Rochester Corporation representative for guidance on cable coiling procedures. The Rochester reply was that, as far as they know, there is no preferred direction in which the cable should be laid.

(U) In view of the difficulty in proceeding clockwise, all* of the cable then in the tank was removed and recoiled counterclockwise.

(U) The cable in the tank covered the entire annular area quite uniformly and was piled about 15 layers high. About 90 percent of the cable was laying

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*The deBell personnel have no recollection of removing all the cable. In fact, their initial narrative was that a figure-8 was made in the tank when clockwise coiling became difficult, and coiling was resumed counterclockwise. This account contradicted later photographs which clearly show the line driver and attached cable going counterclockwise.

in quite nicely -- however, there were several areas close to the inner wall where the cable had residual spring and wouldn't lay down nicely. DeBell cautioned both NUSC and OSI about this phenomenon. In response, deBell was instructed to continue laying the cable as before.

(U) The tank was filled with fresh water** on (approximately) 5 different occasions in order to test the instrumentation electrically.

(U) The cable was then uncoiled from the tank clockwise (last in, first out). It was again brought through the assembly building, as illustrated on the next page, and then out to the flatbed of a truck where it was coiled counter-clockwise.

(U) In the assembly building each instrument cage was refitted. All the D.G. O'Brien connectors were overmolded and both a fuse and T-splice were added to every line. Each refitted package was now tested in salt water.

(U) The array went from the tank to the building by retracing its previous path (see Figure D.5) and went from the building to the truck with the help of a 6 ft. power-driven pulley. The overall dimensions of the flatbed are shown in the diagram below. Bullnoses of 44 in. diameter were fixed at each end and
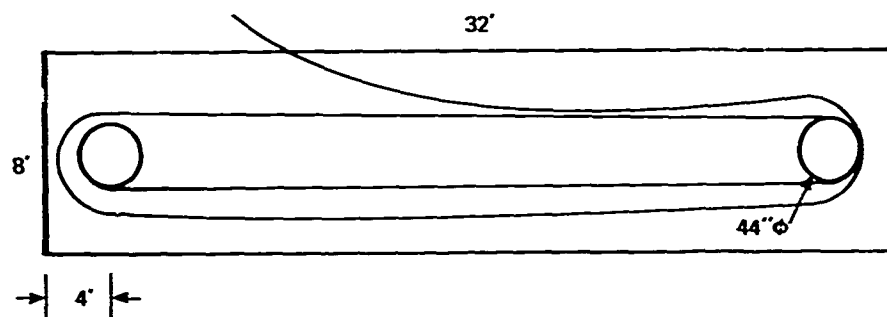

FIGURE D.5 LOADING OF ARRAY ONTO TRUCK FLATBED

the cable was laid around the two stumps as shown in Figure D.5. Thus, the minimum circumference of cable was 2 x 24' + 44 x π ÷ 12, or 60 ft., while the

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**Although salt water wasn't used, the electrical conductivity of the water was high nevertheless. An electrical leak would change the resistance across a typical instrument package from 5 megaohms down to as low as 20 ohms.

LRAPP ASSEMBLY
PRODUCTION LAYOUT

GRASS BELT

TANK

WATER
TOWER

BUILDING 22

MOLDING
STATION

MODEL SHOP

BUILDING 2

6' PULLER

8'

44" OD

TRUCK

32'

SCALE 1" = 20'
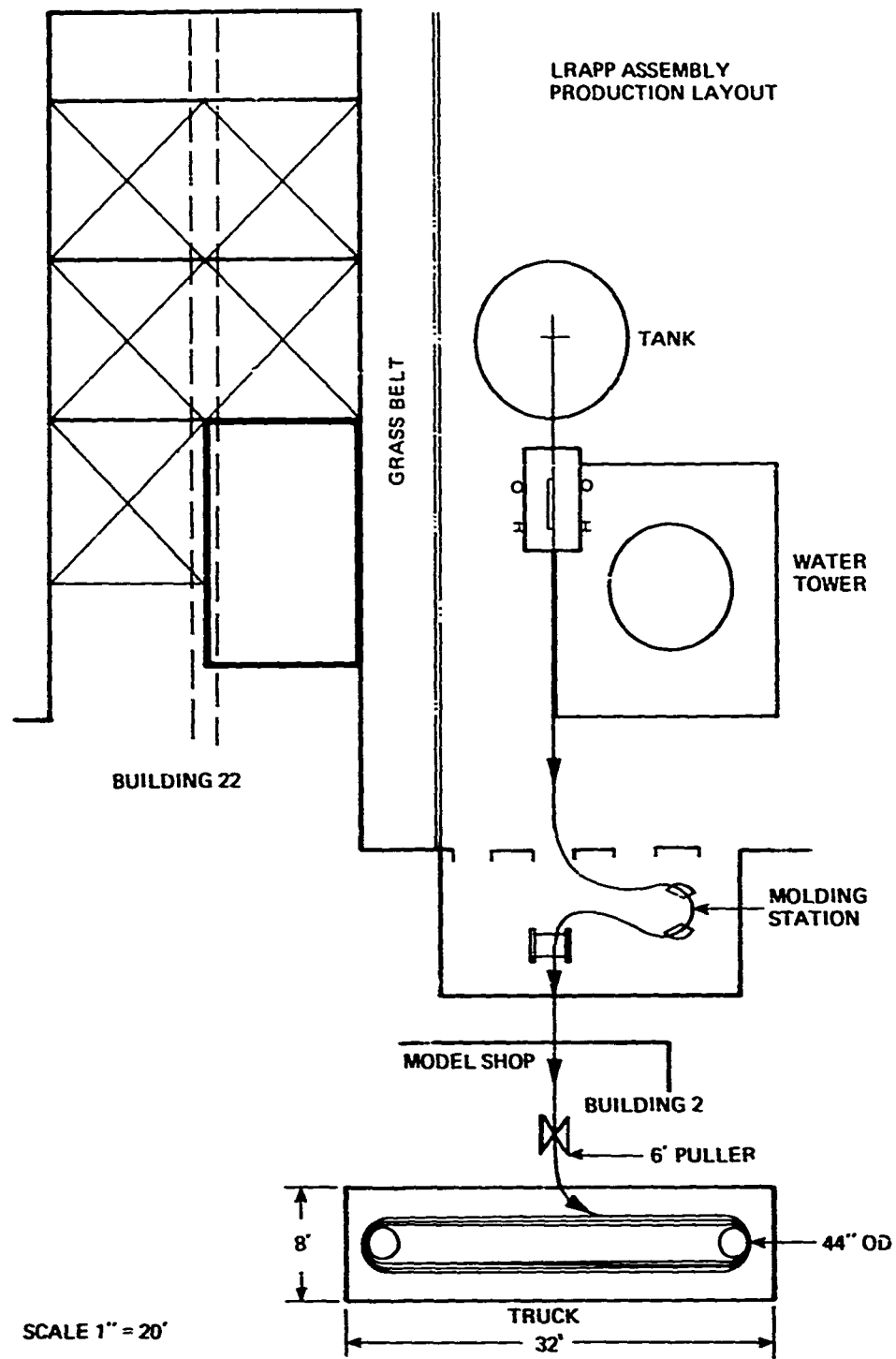
FIGURE D.4   SECOND ARRAY ASSEMBLY

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maximum was about 80 ft. The array cable was coiled counterclockwise in the flatbed. The initial end was purposely left hanging down the side of the flatbed in order that electrical hookups might subsequently be made.

(U) The cable laid exceptionally well in the truck with the exception of a few instances in which a cage segment had to make the sharp turn around the bullnose. Unable to bend the cage segment readily, deBell broke the counter-clockwise pattern by looping the cable just before the bullnose, stretching the instrument package across the truck as shown in Figure D.6, and then continuing in a counterclockwise direction.

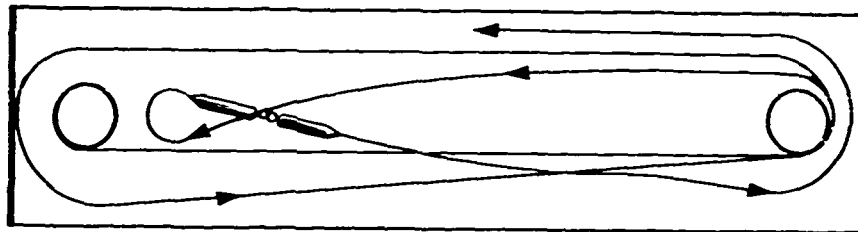FIGURE D.6 LOOPING OF CABLE IN TRUCK FLATBED

(U) An intermediate false deck was built on the flatbed after half of the cable had been laid in order to cut down the load due to the array weight.

(U) During loading of the array on the flatbed a short length of cable connecting two instrument packages was noticed to be bent severely because stiff
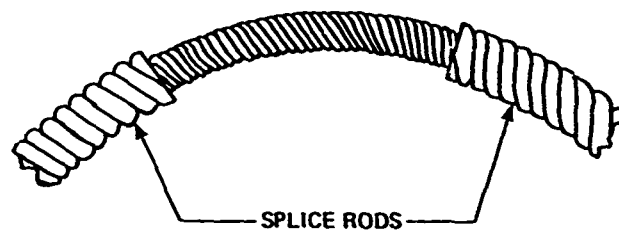

SPLICE RODS

FIGURE D.7 BENT CABLE BETWEEN SPLICE RODS

splice rods within 5' of each other caused a concentration of curvature in the intermediate bare armor when the cable was coiled (Figure D.7). This segment was looped out of the truck in order to facilitate modifications upon completion of loading.

(U) An attempt was made to pot the weak section. In doing this, infrared heat melted the polythelene electrical insulation in the cable. That entire segment of cable was replaced with a new length which was potted under less heat, thereby leaving the polyethelene intact. The overhanging loop was flipped over and onto the remainder of the array in the truck after the above-described modification was completed.

(U) A plywood rim was built around the flatbed in order that the instrument packages might be flooded again for electrical integrity. The truckbed was flooded once with salt water, a second time with fresh water and a third time again with salt water.

(U) After completion of these tests the truckbed was eventually loaded onto an airplane, flown to Bermuda, and brought dockside along the NAUBUC. Because the cable laid nicely in the truck, there should have been no dynamic bending effects during transportation.

(U) The cable was uncoiled clockwise from the truck, led onto the stern of the NAUBUC, 90°+ around a fairlead sheave, across the deck, over a dynamometer, to the 12' diameter drum where it made 4-1/2 turns between the fleeting knives, then across the DOHB, 90° over a 12 ft. diameter radius plate, and through a hole in the deck to the storage tank, as shown in Figure D.8. As before, the cable was coiled counterclockwise in the tank of the ship.

(U) The drum and fleeting knives arrangement provided at least several hundred pounds of tension on the cable at all times, while the DOHB machine provided a traction force estimated (by NUSC) to be several hundred pounds.

(U) As each instrument package approached the middle of the deck, the cable was stoppered off near the stern with a preformed line grip. With the drum and fleeting knives providing the driving force and the DOHB exerting an additional back-up traction, the cable was tensioned at each package to values ranging from 14,000 lbs. to 20,500 lbs.
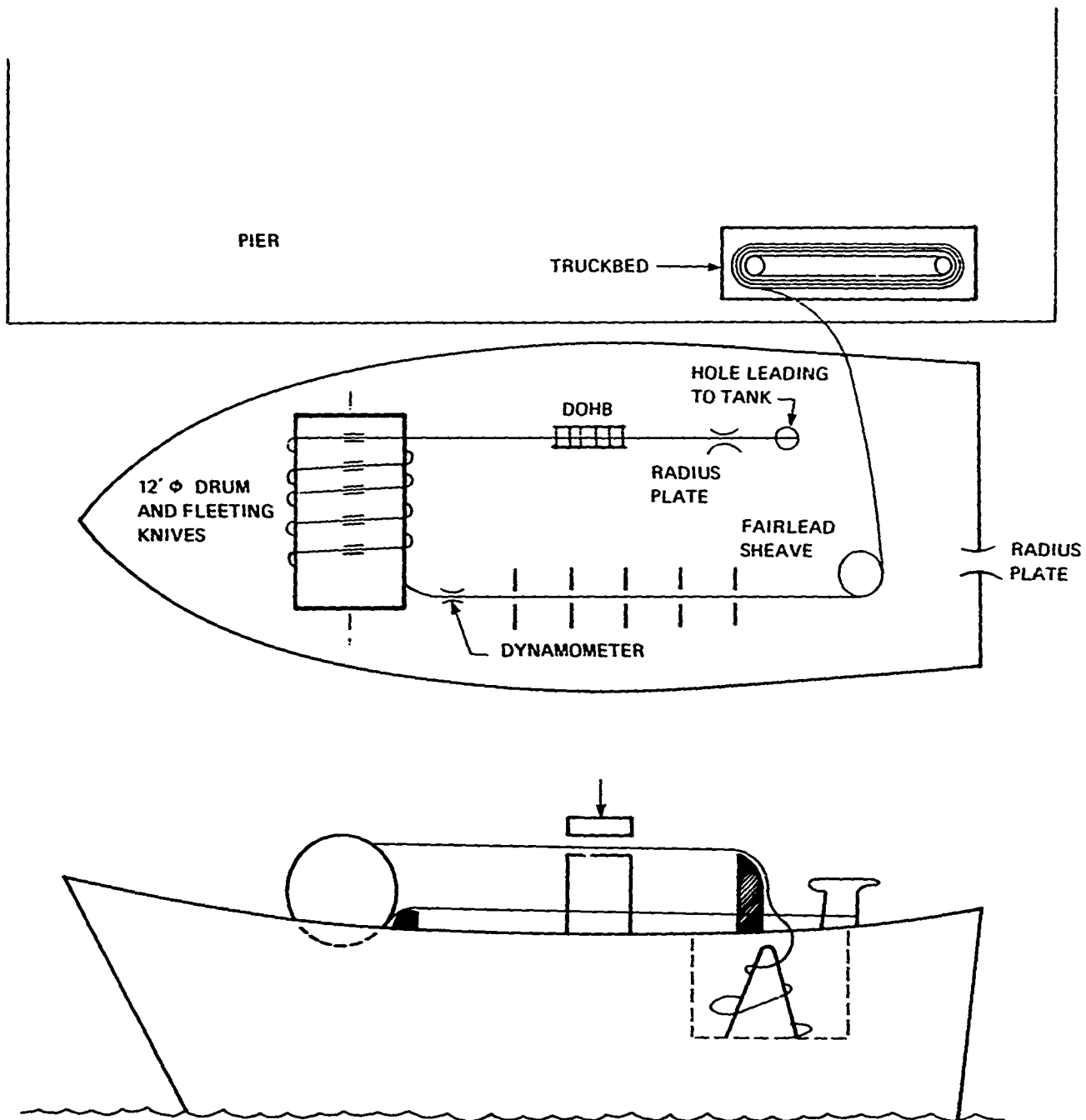
FIGURE D.8   LOADING OF CABLE ONTO THE NAUBUC

(U) Each package was dipped in a salt water trough and tested electrically after tension was released -- in some cases the testing took place before tension was applied while in other cases the test was administered both before and after application of tension -- there is no record of the procedures followed in each case.

(U) Although the cable was free to rotate at the preformed line grip, no rotation was evident either as a result of tensioning the instrument packages or of relieving these tensions, nor were any twisting tendancies discerned during nominal stressing of the array by the drum.

(U) After 11,000' of array cable had been loaded, a twist had built up at instrument package 6H5. The twist was right-handed and tended to tighten the outer (right-hand wound) armor. The twist was relieved by unfastening the ball joint at 6H5 and allowing it to rotate 2-1/2 turns.

(U) The following day another socket was relieved 1-1/2 turns in the same direction.

(U) Later on that day, still another turn had to be relieved, also in the same direction. Only this time, rather than relieving a socket, the truckbed was lifted with a crane and allowed to rotate one turn clockwise (looking down at the truck). Unfortunately, the positions along the array at which these turns took place were not recorded.

(U) The third day 4 more turns were made by rotating the truckbed, and on the fourth day 20 more turns were made. No turns were made on the 5th and last day of loading*. Again, the positions along the array at which the turns took place were not recorded.

(U) Table 5 gives the number of turns made on each day of loading together with the total number of feet of cable laid that day. Note that the data on number of turns is that of deBell while the length of cable payed out on any one particular day is NUSC's data. The latter showed no turns the first day, an unspecified number the second, one the third day, an unspecified number

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*There is no record of how many times, if any, the end of the array was rotated.

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greater than 20 the fourth day and none the last day. The deBell data is
used in the table because it is more definitive, thus seemingly more accurate.

Day	No. of cable turns that day	Cumulative no. of cable turns	Amount of cable loaded that day	Cumulative amount of cable loaded
1	2-1/2	2-1/2	11,000'	11,000'
2	2-1/2	5	6,000'	18,000'
3	4	9	5,500'	23,500'
4	20	29	7,000'	30,500'
5	0**	29	4,500'	34,500'

TABLE 5. CABLE TURNS DURING LOADING

**The cable was allowed to turn freely as the end was reached -- see previous
footnote.

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APPENDIX E

ARRAY CABLE IMPLANTMENT TENSIONS

(U) The implanted Test Bed is sketched in Figure E.1. Details omitted
are not germane to this discussion and may be found in reference (3).

FIGURE E.1 IMPLANTED TEST BED

(C) Payout and implantment of the array cable commenced when point 0 on
the grapnel line, 14,400' out from the offshore anchor, touched bottom while
the offshore anchor A was put overboard. Array cable implantment ended
"officially" when the line driver L touched bottom, corresponding to payout
at G, approximately 20,500' inshore from L. Payout points along the cable at
which significant discontinuous changes in array cable tension took place were:

    A - Corresponding to offshore anchor deployment
    B - Corresponding to offshore anchor touchdown
    C - Corresponding to offshore buoy deployment
    D - Corresponding to inshore buoy deployment
    E - Corresponding to inshore anchor deployment
    F - Corresponding to inshore anchor touchdown
    G - Corresponding to line driver touchdown

the sketches in Figure E.2 are of typical array configurations during intervals
$\widehat{AB}$, $\widehat{BC}$, ..., $\widehat{FG}$.
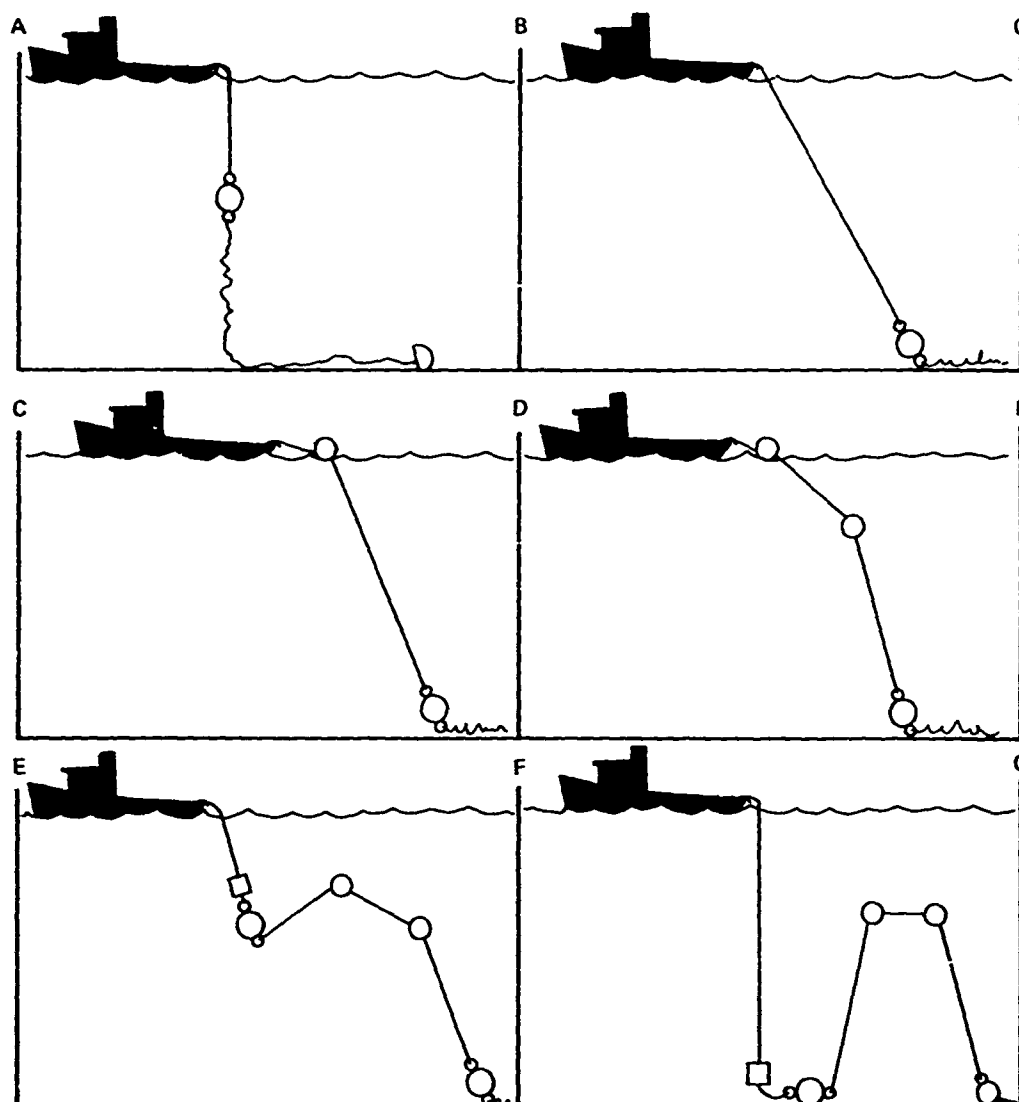
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Figure E.2   PHASES OF IMPLANTMENT

(U) Tensions in the array segments during implantment were as follows:

$\overline{AB}$ Payout:

(U) Tensions in $\overline{AB}$ ranged from 3,000 lbs. to 14,000 lbs. during
the first 9,000 ft. of payout, then remained in the narrower
range of 5,500 lbs. to 8,000 lbs. as the seas calmed down
till offshore anchor touchdown. The five irregularities
cited in the body of this report for the offshore leg all
took place before anchor touchdown.

$\overline{BC}$ Payout:

(C) At offshore anchor touchdown payout was at point **B**, 14,400 ft.
up that leg. The tension at B was reduced from the 6,000-8,000
lb. range down to 1,000 lbs. Tensions during payout of the
remainder of $\overline{BC}$ never got above 1,000 lbs. and went down to
zero on several occasions. There were no significant irre-
gularities during this segment of payout.

$\overline{CD}$ Payout:

(C) The offshore buoy was attached at point C, the end of the
15,400 ft. offshore leg. The weather was smooth and the ship
was rolling no more than 5°. Tensions at the point of pay-
out were in the 500-1,500 lb. range, implying from statics
principles that tension in the offshore leg ran 1,000-3,000
lbs. Three irregularities occurred as this horizontal leg
was payed out (see Discussion).

$\overline{DE}$ Payout:

(C) The inshore buoy was attached at point C, the inshore end of
the 3,000 ft. horizontal leg. The weather was very calm
throughout payout. The tension on the inshore leg was 1,200
lbs., implying tensions in the 2,000 lb. range for the
horizontal leg and in the 3,500-4,000 lb. range for the off-
shore leg during this interval, based on the static configura-
tion. Five irregularities were observed during payout of
the inshore leg.

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$\overline{\text{EF}}$ Payout:

(U) Upon payout of the inshore anchor and chain, the cable tension increased to 5,000 lbs. at the point of payout and subsequently ranged from 4,000 to 6,000 lbs. while there was a beam sea and the ship was rolling 5 to 10°. By this time the array itself was totally submerged and approaching its final configuration so that all three legs were under several thousand pounds tension.

(U) **The tension** at payout then built up to 7,000 lbs. (recall that SDC cable weighs 137 lbs. per 1,000' of length), still in calm water. Eventually the winds increased to 20-25 knots and the sea began to build up. At the half way point of lowering the inshore anchor the tension at payout stayed between 6,000 and 8,000 pounds.

(U) When the inshore anchor was (calculated to be) 1,500' off the bottom the tensions at payout were increasing to the 7,000-8,000 lb. range, and at 1,000' off the bottom, the weather got so rough that the ship was rolling up to 30°. The tensions at payout now ranged from 3,600-9,000 lbs. Readings from the depth gage at the inshore buoy showed that point to be at 2,600 ft. depth -- hence, there was definitely no slack in any of the array elements.

(C) Payout was continued with the ship hovering in the same position. At the payout point calculated to correspond to the inshore anchor touching bottom there was no corresponding reduction in tension. Moreover, the depth gage showed the inshore buoy to be at 3,600 ft. depth -- in its final geometry it should be at 4,100 ft. depth.

$\overline{\text{FG}}$ Payout:

(U) Upon additional payout of SDC cable the inshore buoy rose to 3,570 ft. depth. Consequently the ship started paying out SDC cable with negative slack till the inshore corner location

stabilized at 3,800 ft. By this time the storm got so violent that tensions at payout never did drop to the range merely corresponding to the weight of the suspended SDC cable in water -- which would have indicated that the anchor had definitely touched down. Payout tensions during the next day of cable laying ranged from 0 to 10,000 lbs. The final weighted chain attachment was not made because of the rough seas.

(U) The inshore array corner held at 3,800 ft. depth as additional cable was laid. The seas then moderated gradually.

APPENDIX F

ALTERNATE POSSIBLE CAUSES OF CABLE TWISTING

(U) The reason the severe twists formed in the array cable during payout is very definitely linked to the reason it also twisted during loading. The following possibilities for loops forming in the array cable during loading, other than that given in Section 3.4, are listed and examined:

(1) The twists were already present in the cable as a result of manufacture. This possibility does not appear likely since, during array fabrication, cable lengths less than 200 ft. in length were laid out flat coming off the reels and no looping was observed (see Appendix D). The only way to resolve this possibility for sure would be to unreel a long length of the actual cable and measure any untwisting. Perhaps a white line painted down one side of the cable during manufacture would provide a convenient tracer. If, indeed, residual twists were induced during manufacture, this does not explain why they first manifested themselves during loading and not any sooner, say, during transfer onto the truck flatbed.

(2) The twists were put in the cable during array fabrication. The array was fabricated from cable lengths that were either laid out flat or were wound on reels. Furthermore, no twists were induced at the sockets during assembly, so it appears unlikely that twists were put into the cable during array fabrication.

(3) Twists were put into the cable during handling between the time of array fabrication and that of loading.

As was explained earlier, coiling of cable induces a twist per unit length which is eventually removed during uncoiling. The array cable was coiled counterclockwise in all instances, tending to loosen the outer lay of right hand wound armor or

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give the cable a left hand twist. It might be conceivable
that some of the twisting "worked itself out" through the
two free ends of the cable while it was coiled in the tank
at the array fabrication site or while it was in the truck
flatbed, and that there was residual right hand twist when
the cable was subsequently uncoiled. This does not appear
likely, however, because (a) the cable coiled very easily
-- there did not appear to be enough "springiness" to pro-
pagate back toward the cable ends, (b) any such effect would
be reversed after uncoiling, (c) one end of the cable was
attached to a massive line driver which would have inhibited
any rotation tendancies. In any case, 20 turns could not
have been induced in this manner.

(4) The twists were hysteresis effects resulting from several
cycles of reeling and coiling.

The cable certainly was subjected to a significant amount
of handling up until payout, highlighted by two complete cycles
of coiling. However, it is logical to believe that, if
hysteresis produced residual torque as a result of manually
coiling the cable, that the torque would be too insignifi-
cant to inhibit further handling of the cable and would be
"worked out" during subsequent tensioning. Such was not
the case. Furthermore, it is difficult to believe that there
would have been no inkling of the onset of hysteresis effects
after the first cycle of coiling.

(5) The twists were induced by coiling the cable into the tank
of the ship. This does not seem reasonable because the
tank of the ship hae even less curvature than the tank at
the array fabrication site where coiling produced no observ-
able twists propagating back out of the tank.

(6) The twists were torquing effects due to tensioning aboard
the ship. Tensions in the cable going through the ship's
machinery during loading were too low to cause torquing.
The instrument cages were tested under significant tension

but this tension was between two fixed points on the cable
in every case. Any torquing due to this tension would then
be negated as a result of tension release.

APPENDIX G

STRUCTURAL BEHAVIOR OF THE LRAPP ARRAY CABLE

(U) The double-armored array cable mechanical properties of importance in connection with the loadings identified in Table 2 are now considered. Based on the extent to which these properties are known, the cable's structural and electrical integrity under the actual loading encountered is evaluated.
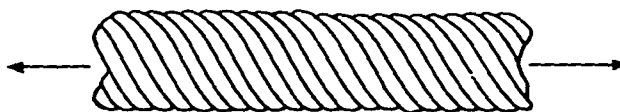
(1) Tensile strength and stiffness.

FIGURE G.1 TENSION ON DOUBLE-ARMORED CABLE

(U) High tensile strength is never undesirable, but it may not be totally meaningful unless the cable maintains complete electrical integrity up to the design tensile stress. Such a condition may be difficult to ascertain. For example, the outer conductor may be weakened mechanically to the point where it fails under subsequent loading, although electrical tests performed at the time indicate nothing negative.

(U) Armoring of cable increases its strength and its stiffness. It is desirable for the tensile modulus of the armor to be much greater than that of the electrical part of the cable since, in this case the former will carry most of the applied tension.

(U) The array cable has a minimum 30,000 lbs. rated breaking strength. However, specifications do not indicate whether or not electrical integrity is maintained to the full 30,000 lbs. The maximum cable tensions encountered were well under 20,000 lbs. (see Appendices D and E), so it seems unlikely that its electrical integrity was exceeded.
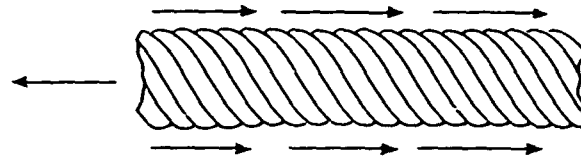
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(2) Traction.

FIGURE G.2 TRACTION

(U) Longitudinal shear, or traction forces (shown in Figure G.2) are produced when cable tension is resisted by a DOHB* machine. In the case of unarmored cable, the normal forces which are provided in order to create the traction force are usually of more concern because the low stiffness dielectric may distort under the crunching effect. Cable armor has a very positive value in this regard, but the sliding effect of one layer of armor over another due to the traction force may produce distortions or residual torque which can complicate subsequent handling.

(U) There are no specifications for the maximum allowable traction force on healthy array cable. The effect of such cable with a hockle already in it is not known, but it does not appear to be beneficial. Actual traction forces encountered were in the range of 1,000 lbs.
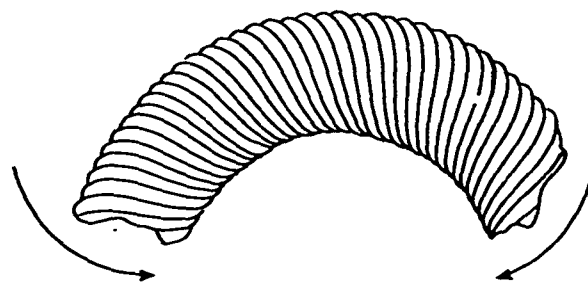
(3) Flexural properties.

FIGURE G.3 FLEXURE

*Draw-off-hold-back, also called a "caterpuller" or a linear traction machine.

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(U) Generally speaking flexibility is a desirable cable property. However, excess bending of cable can be most detrimental if the center conductor "filets" through the inner dielectric. For this reason the maximum allowable curvature to which cable should be subjected is usually specified by the manufacturer. Armoring of cable may be beneficial in that it requires a greater bending moment to achieve the same radius of curvature. Added bending stiffness might protect the cable during handling. However, the stiff outer armor may actually crimp the outer dielectric before the minimum bending radius is achieved, thereby causing permanent set and possibly initiating electrical damage. Therefore, one cannot say a priori whether or not armored cable can take a greater bending moment then unarmored cable.

(U) The bending capacity of armored cable versus unarmored cable also depends on which is prescribed -- the bending moment or the bending curvature. For example, cable loaded onto a reel has a prescribed curvature while cable bent around a sheave may be force-controlled. In the former case armoring can never be beneficial, while the latter situation armor may indeed be helpful.

(U) The cable was qualified to a minimum 12 inch bending radius. There is no indication of any associated test procedure but the cable appears to accommodate a 12" radius with little effort. The minimum handling radius was also 12 inches.
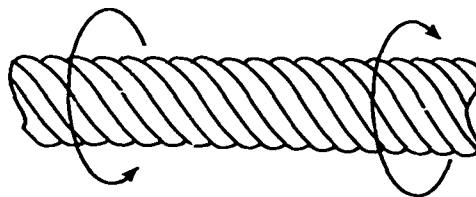
(4) Torsional properties.

FIGURE G.4   TORSION

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(U) The torsional resistance of cable is usually so low compared with the applied torque that it is convenient to think of external torsional effects as twist-controlled rather than torque-controlled. For this reason it is desirable to have a cable as limp as possible and which will also accommodate as much twist as possible.

(U) Double-armored cable will have increased torsional stiffness* over unarmored cable and will usually not accommodate as large an angle of twist as the latter. Furthermore, when subjected to a torque in a direction tending to loosen the outer armor, the inner armor will cut into the dielectric while the outer armor will birdcage. This condition (a) raises doubts about the cable's electrical integrity (b) reduces the cable's subsequent tensile strength to that of the inner armor (c) can cause numerous problems if the cable is subsequently reeled or pulled around a sheave, pulley or radius plate under tension. When subjected to a torque in the opposite direction the outer armor strands tend to separate while the inner armor tries to pop through the opening. The net effect is a hockle**, with the cable's electrical integrity seriously in doubt, and with its tensile strength reduced substantially. An extreme case of either a birdcage or a hockle is a kink. Kinks cannot be tolerated; they require both stress relief and an electrical bypass.

(U) One significant implication of armored cable's increased torsional stiffness is that it can't be coiled to as great a curvature as its unarmored counterpart. A second consequence is the phenomenon of torquing, which will be discussed shortly.

(U) The maximum design twist according to the implantment plan was about 53 turns per thousand feet, corresponding to coiling around the inner circumference of the tank at the array fabrication site. The maximum twist the cable actually was subjected to is not known, but obviously it was too much. There is nothing known about the maximum allowable twist for the cable, nor was there any specification for same.

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*Of course the right hand and left hand twist characteristics of armored cable are not necessarily the same.

**See Appendix A

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(5) <u>Combined tension and flexure</u>.
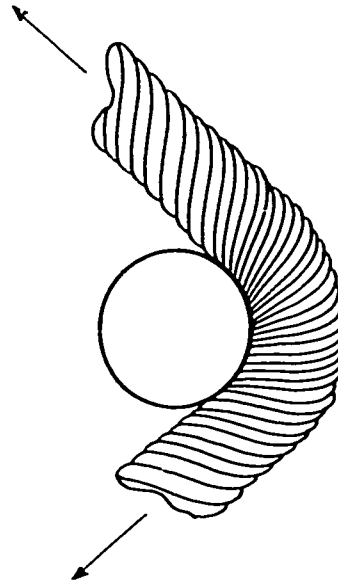
FIGURE G.5   COMBINED TENSION AND FLEXURE

(U) Combined tension and bending, as the case of a cable which is reeled, passed over a pulley or sheave, etc., can lead to the fileting effect described earlier, only at a smaller curvature. A cable's maximum allowable tensile force should be determined as a function of radius of curvature to which the cable will be bent.

(U) If the bending radius is within the design limits of the cable in the absence of tension forces, then the armor will have a positive effect when tension is applied. It will carry most of the applied tension as well as distribute the bearing forces at the bend.

(U) The worst identifiable combined tension and bending stresses on the cable seem to be as follows:

   a. Possibly several thousand pounds tension on the manu-
    facturer's 3 ft. diameter reels.

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b. Possibly several hundred pounds tension on reels at the array fabrication site.

c. Possibly 10,000 lbs. tension over the dynamometer.

d. Possibly 15,000 lbs. tension around the 12 ft. diameter stern chute.

(U) There were no combined tension-bending integrity requirements set in the specification nor are design interaction curves available.

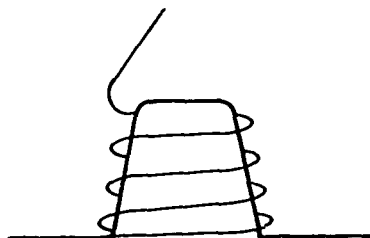(6) Combined bending and torsion: Coiling.

FIGURE G.6 COILING

(U) Coiling of cable is a combination of bending and torsion.* The cable is twisted 360° for each 2π times its bending radius. The extent to which unarmored cable can be coiled is determined by its allowable bending radius and its allowable twist per unit length considered separately.

(U) Coiling of double-armored cable, on the other hand, tends to tighten one lay of armor while loosening the other lay. In the case of the Test Bed cable, for example, clockwise coiling tightens the outer right-hand armor and loosens the inner left-hand armor. Double armor cable will be very lively when coiled since one lay wants to elongate while the other lay wants to shorten. It will generally lay better when coiled in a direction which tends to loosen the outer lay (note from Appendix D that the Test Bed cable was coiled counterclockwise in all instances because it was "easier", thereby confirming the above statement). However, reference [22] recommends handling of double armored cable only on reels because of its liveliness when coiled.

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*See Appendix A

The cable was subjected to a minimum coiling diameter of 8 ft. There are no minimum allowables set by the manufacturer nor did the specifications call for any.

(9) <u>Combined-tension and torsion: Torquing</u>.
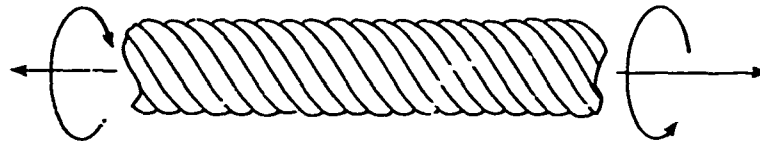
FIGURE G.7 COMBINED TENSION AND TORSION

(U) Pure applied torsional forces on a length of cable require un- restricted end shortening. Cable can accommodate such forces by forming loops. However, any restraint against end shortening results in tensile forces in addition to torsion. In practical situations there is usually some restraint against end shortening. Therefore, in speaking of a cable's torsional re- sistance one usually has to say something about the state of tension as well.

(U) In discussing combined tension and torsion on cable, however, the phenomenon of principal interest is <u>torquing</u>, which is the propensity of cable to twist under pure tensile forces or to build up torque when subjected to pure extensional deformation. Because of the significance of torquing as a very high risk aspect of the implantment, this phenomenon and its possible effect on the array cable are considered in section 4.5.

(8) <u>Hysteresis</u>.
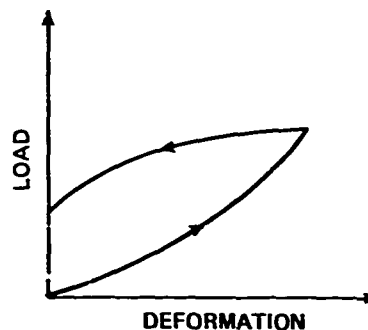
FIGURE G.8 HYSTERESIS CURVE

(U) Cable is not classical linear elastic material. It twists under pure tensile forces; its torsional properties in each direction are different. Furthermore, its loading and unloading curves trace different paths on the deformation curve whether the loading is tension, torsion, bending, traction or combinations of these. In fact, even a highly engineered cable such as SDC* exhibits significant differences between its loading and unloading curves.

(U) It is possible that, within limited ranges of loading, certain cables will faithfully reproduce their stress-strain curves, but this phenomenon should be proven experimentally for the specific cable and for the specific range and history of loading -- it should not be taken for granted.

(U) The principal implication of hysteresis is that a cable's behavior under several cycles of combined loading cannot be predicted without simulated prototype testing. Needless to say, nothing was known about the "memory" of this particular cable. The need for such knowledge is obvious.

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*See Reference [21].

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13. ABSTRACT

The report is a diagnosis of the LRAPP Test Bed array cable failure. The high risk aspects of the Test Bed implantment that are identifiable with the array cable's properties or its handling are considered, and the particular cable properties which had major influence on the implantment are identified and their effect analyzed. Methods for retrieval of the Test Bed are discussed and recommendations are provided for enhancing the certainty of success for future suspended array implantments. (U)

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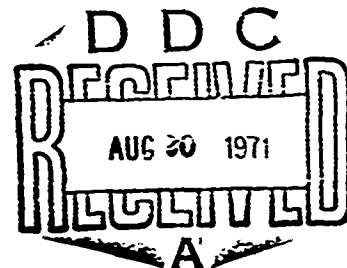
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